50 YEARS' EXPERIENCE

Sheet Metal Fabrications
Stamping
Machine Work
Electrical Assembly
Wiring and Testing
Welding
Paint Finishing
Products Completely Manufactured

They* were going to draw this X-Ray Control Housing 14" x 7" x 7". Dies to properly handle 1/16 inch steel cost $4200. We were asked to suggest something. We said—"Fabricate it at a tooling cost of $140." The Manufacturing cost proved to be in line, precision held was + or — .005, the customer saved a lot of money.

Perhaps your product too,—or part of it—could be fabricated, with comparable savings. It's well worth thinking about and enquiring about. Especially these days with die-making at a premium. Also out of that wide range of specialized skills listed in the box at the left we might engineer other valuable product improvements and economies for you.

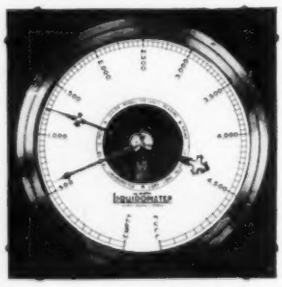
*(Name upon request)

BIG *names in American Industry are customers of ours—for many years too!*

LEWYT METAL PRODUCTS CO. Inc.
60 Broadway Brooklyn, N. Y.

The Importance of Accurate Liquid Control Demands A **LIQUIDOMETER** *The Dependable Tank Gauge for All Liquid Measuring*

Many satisfied industrial users attest to the perfect year in and year out efficiency of their LIQUIDOMETER tank gauges. Convenient, hazard-free, 100% Automatic—these tank gauges insure accurate readings whenever required.



No pumps, valves or auxiliary units required to read levels. Balanced hydraulic transmission system completely compensates for temperature variations on communicating tubing. Accuracy unaffected by changes in specific gravity.

Approved for gauging hazardous liquids by Underwriters' Laboratories and other similar groups.

Models are available for REMOTE signals, automatic control of pumps, etc. Direct Reading models may also be installed where remote reading is not desired.

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36-27 SKILLMAN AVE. LONG ISLAND CITY, N. Y.

Instruments
THE MAGAZINE OF Measurement and Control

Vol. 14 MAY 1941 No. 5

FRONT COVER: A corner of the new Instrumentation Laboratory at Case School
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ADVERTISERS' INDEX ..... (Insert)

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THE INSTRUMENTS PUBLISHING COMPANY
1117 Wolfendale Street, Pittsburgh, Pa.

RICHARD RIMBACH, Managing Editor — **M. F. BEHAR**, Editor

BRANCH OFFICES

Boston: James Condon, 36 Myrtle St. (Lafayette 0829).
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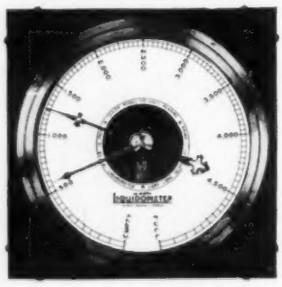

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Instruments THE MAGAZINE OF Measurement and Control

M. F. BEHAR, Editor

Bandwagon?

WITH almost dramatic suddenness, courses in various types of measurements and metering, and even in automatic control, are springing up throughout the country. The *proximate* cause is the vital necessity of converting untrained youths into specialized workers and of re-training numerous classes of adult workers. Thus, in one sense, the springing up of these courses is "only a by-product" of the Defense effort. In support of this view, there is the indisputable fact that courses in gaging, and in various physical tests, predominate.

This view is neither entirely false nor entirely true.

That it is not entirely false is evident from the fact that, in 1915-17 there was a similar spurt in the training of testers and inspectors. Since it was not until 1924-1929 that Instrumentation began to be formulated as a distinct science or a distinct branch of engineering, what is happening now might be "simply history repeating itself."

But it is not entirely true: Courses during the First World War were derived from Metrology. Today's courses are derived from Metrology *cum* Instrumentation.

Metrology might be called the science of measuring dead things like a gear pitch diameter, a thread angle, a grain size, a yield point, a scratch hardness, etc. Instrumentation begins with measurements but it goes on to deal with "living" things in industry—like furnaces and stills and vulcanizers and all kinds of active machinery and equipment. Instrumentation deals with their behavior. One of its aims is to make them behave.

"Hold on," says the Engineer, "That's the province of Engineering. It takes a chemical engineer to make a still behave. It take a mechanical engineer to make a turbine behave and an electrical engineer to make the driven generator behave. Only a radio engineer is capable of designing and operating a broadcasting station . . ."

Okay! We get the point. But there's no argument: it's all a question of horizontal and vertical fields. The management engineer, for example, serves all major occupational groups. Instrumentation likewise cuts across the boundaries. To a competent instrument engineer, holding the assigned frequency of a broadcasting station "on the nose" and holding fractionating-tower temperatures and flows "on the nose" are two similar problems in Automatic Control. Their solutions are based on the same Instrumentation fundamentals as are solutions of problems involving the automatic control of pressure and pH and plasticity and pickling and polymerization—and processing in general.

Today's courses *are* different! In the first place, even the courses in dimensional gaging which start with Metrology go on in some instances to deal with "live" automatic gaging devices which are fruits of Instrumentation. In the second place there are new courses in the use of spectroscopes, x-ray machines and other modern instruments. In the third place there are courses in Measurement-and-Control, officially called courses in Instrumentation (see page 122). And in the fourth place, engineering educators as a profession are at last "recognizing" Instrumentation.

We never doubted that this recognition would come. We predicted it 'way back in 1924 (when the word "Instrumentation" offended most professorial ears) because of the inspiration we received from a high-minded and far-seeing pioneer in technical education: the late Nissim Béhar. But after having been laughed at by most engineering professors during the decade 1925-1934; and after seeing in recent years the exasperatingly slow percolation of our postulates throughout academic circles, we confess that we are startled by the sudden rise in interest—like one of those chemical processes that smolder for hours then go blooey if you don't add the inhibitor at the right moment. Yes, it looks like they're jumping on the bandwagon.

Whose bandwagon? Perhaps that of any politician shrewd enough to produce a shiny vehicle and label it "Official Car." That's usually the way it goes.

But there are signs that the movement will not get out of hand; for the hands being stretched out to grasp the reins of its guidance are experienced hands. We refer, for example, to the Society for the Promotion of Engineering Education, which has just placed discussions of instrument courses on the schedule of two meeting this summer: at Ann Arbor and at Purdue. The S.P.E.E. is an authoritative body, charged with great responsibilities and hence somewhat conservative. That is all to the good!

There is also under way a project to hold a "mixed" conference of engineering educators and of Instrumentation-minded industrial executives and engineers, later this summer, which conference would be entirely devoted to the subject of Instrumentation courses in schools, colleges and universities. This is not a sudden bandwagon but a plan conceived several years ago. Analysis of the replies to the first batch of invitations seems to show that in spite of pressure of work and numerous other engagements, competent and enthusiastic representatives of education and industry will find time to prepare written contributions or to come with the intention of presenting discussions.

In recent conversations with engineering professors who are giving Instrumentation courses, we were asked to sum up "in a word" the difference between Instrumentation and the use of instruments. The word "life" might do it, as hinted a few paragraphs back on this page, or as appears when the study of automatic control is taken up (see pages 123-126 in this issue). One criterion we suggested was that in an instrument laboratory (metrology sense) the students measure dimensions, properties of matter and even variables, but in an Instrumentation laboratory they would study Automatic Control by working with "living" apparatus like the one suggested by Fig. 1 on page 124.—MFB

Meeting Notices

American Society for Measurement and Control

The Annual Meeting of the Society will be held Monday evening, May 26, 1941, at 7:45 p.m., in the Bureau of Mines Auditorium, 4600 Forbes St., Pittsburgh. (Ample parking space in *rear* of building.) The tellers will report the results of the letter ballot and the new officers will be installed. The rest of the varied program is expected to interest members in all industries.

Chicago Society for Measurement and Control

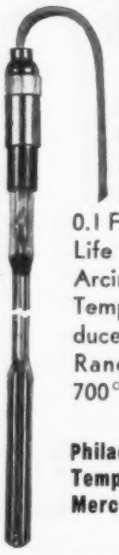
2626 W. 31st Blvd., Chicago. (Phone Canal 4100)

Officers for 1941-42 are: Pres.: E. C. Rieger (Int'l Harvester); V-P: Wm. Douglas (Inland Steel); Treas.: W. Brock (Socony Vacuum); Sec'y: H. A. Hulsberg (Univ. Oil Products).

Eastern Photoelasticity Conference

The Thirteenth Semi-Annual Meeting will be held on June 12, 13, and 14, 1941, at Cambridge, Mass., under the auspices of the Department of Mechanical Engineering at the Massachusetts Institute of Technology. Address inquiries to W. M. Murray, Room 1-321, M. I. T., Cambridge, Mass.

Philadelphia Merc-to-Merc Thermo-Regulators Feature



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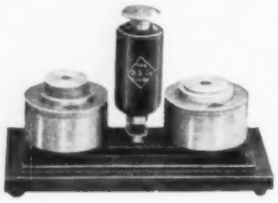
R. S. DEAD WEIGHT GAUGE



Designed for measuring gas pressures, and can be put on a line at any connection where an ordinary gauge is placed. This gives the exact pressure in a line by actual dead weight.

For full description of new gas testing instruments and laboratory apparatus, write for catalog No. 26-A.

THE REFINERY SUPPLY CO.
Manufacturers, Jobbers and Importers Scientific, Laboratory and Power Plant Equipment
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1309 Capitol Ave. Houston, Texas

THE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control.

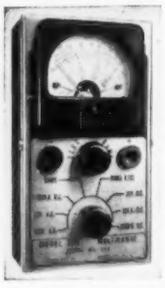
When writing to manufacturers directly, please mention this department as your source of information. Or write to Information Section, Instruments Publishing Company.

Resistance Standards

New "800 Series" Resistance Standards are calibrated resistances from 1 ohm to 10 megohms in single units and in various combinations. They are designed for d-c.

electrical measurements and for a-c. measurements at frequencies up to 20 kilocycles. They are said to provide physicists, electrical engineers, chemists, and others with dependable apparatus for electrical measurements in research, engineering, teaching and testing.—*Shallcross Mfg. Co., 10 Jackson Ave., Collingdale, Pa.*

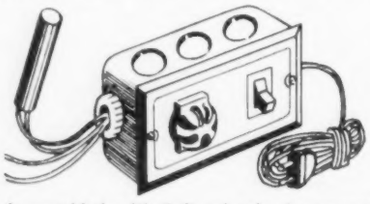
General-purpose Tester



New "Model 323" is a pocket-size general-purpose a.c.-d.c. instrument for radio and electrical measurements. Stainless steel panel and welded steel case. Fully insulated. Dimensions 2⅞"×5¼" ×1⅞". Shipping wt. 2 lbs. — *Triumph Manufacturing Co., 4017-19 W. Lake St., Chicago, Ill.*

Cartridge Type Thermostat

Newly announced "Pilotherm" contains a snap switch and box, pilot light and "Cartridge Type" thermostat (⅝" × 2¼" long) assembled and wired ready for installation.



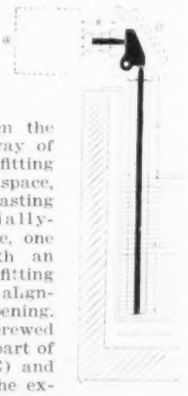
It is provided with 3 ft. of asbestos-covered nickel-stranded wire between the cartridge type thermostat and the switch box, 3 ft. of nickel wire for connection to the heater terminals and a 6 ft. rubber cord set at the input end of the switch box. Designed for 500 watts, 115-230 volts a.c. Available for maximum operating temperatures of 300, 450 and 700°F. For use on hot plates, hot tables, melting pots, molding presses and other electrically heated machines.—*George Ulanet Co., 89 East Kinney St., Newark, N. J.*

Photoelectric Lighting Relay

New photoelectric relay for lighting and power, designated "Sun-Switch," is for control in accordance with rise and fall of natural illumination. User chooses the two lighting levels at which he wishes the load switched on and off, and adjusts the calibrated dials to the corresponding foot-candle readings. Operation is entirely automatic. Housing is weatherproof drawn metal, 10¾" × 5⅝" × 3½". Door gasket is cork, and finish of box, aluminum. Hasp permits padlocking. The control circuit uses a type 921 phototube (life expectancy of 20,000 hours) and two type 6J5 tubes (5,000 hours). Operation is from 110 volts, 50- or 60-cycle a.c. — *United Cinephone Corp., Torrington, Conn.*

90° Adapter for Stem-type Temperature Controller

Purpose of new "Klosefitting Heat Control Actuating Elbow or Angle Fitting" is to permit attaching a vertically-positioned primary-element assembly of a temperature control instrument to a kettle, pot or other heating container in such a way as to keep the tube of the instrument as close to the side walls of the pot as possible—away from the heat and out of the way of work at all times. New fitting (C) occupies minimal space, consists of a hollow casting containing a specially-designed fulcrum device, one end in alignment with an opening in bottom of fitting and the other part in alignment with a side opening. Into bottom outlet is screwed the active or sensitive part of the controller tube (DE) and into the side opening the extension tube (B) whose other end is attached to the instrument head (A). Elbow fitting is said to be "so perfectly balanced that the slightest contraction or expansion of the tube instantly actuates the lever in the ell fitting which in turn continues the proper expansion or contraction movement to the upper or main working control parts of the instrument." New device makes it possible to locate the head assembly in any desired position around the heating pot or vessel without taking up any more than 1" space (from edge of pot to outside of tube). This fitting is made for use only on maker's line of instruments.—*Burling Instrument Co., 241 Springfield Ave., Newark, N. J.*



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(Patented Circuit)

RADICAL BRIDGE DEVELOPMENT

Featuring Electronic Cosine Galvanometer and Electrical Triangulation

Measures Capacity, Power Factor, Phase Angle, Resistance, Inductance and Frequency. Indicates Synchronism. Null system employed to indicate bridge balance, same as in conventional D.C. bridge. Invaluable for use in schools, laboratories, and inspection departments.

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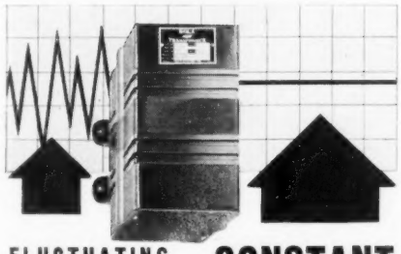


FLUCTUATING LINE VOLTAGE

CONSTANT VOLTAGE

Whether it's 1 VA for an instrument or 10 KVA for a Production line—here's constant, stable voltage for you at all times, even though the line voltage varies *as much as thirty percent.*

They are fully automatic and instantaneous in operation—have no moving parts—require no maintenance—and are self-protecting against short circuit.

You can build a SOLA CONSTANT VOLTAGE TRANSFORMER into your product, or incorporate it in your production line or laboratory and know that every test will be made under identical line conditions.

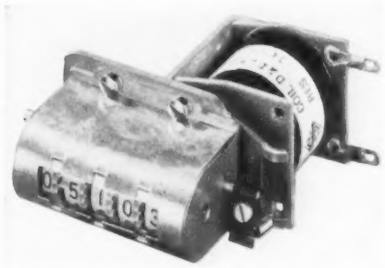
Compact—economical. Standard designs are available, or units can be built to your special specifications. *Ask for* **Bulletin GCV-74**

SOLA ELECTRIC COMPANY
2525 Clybourn Ave. Chicago, Ill.

SOLA
Constant Voltage
TRANSFORMERS

Electric Counter

There is announced "a new inexpensive electrical counter as a companion piece to line of Autelco Jr. Relays." New counter is known as the "Autelco Jr. Counter" and is



built for high speed a.c. or d.c. operation. It is of the non-reset type, counting up to 99,999 and then repeating. Maximum operating voltage, 240 volts d.c. or 50-60 cycle a.c. For a-c. operation, maximum speed is 15 steps per second; for d-c. operation, 20 steps per second.—*Automatic Electric Co., 1033 West Van Buren St., Chicago, Ill.*

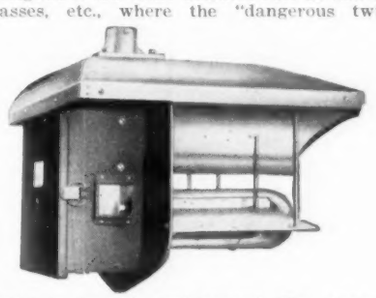
Tension Dynamometers

Two series of tension dynamometers are announced. "Model A," 5" dial diam. and weighing 4½ lbs. is available in seven ranges: lowest 0-2500 lbs. in 50-lb. divisions and highest 0-15,000 lbs. in 125-lb. divisions.

"Model B" is available in 0-500, 0-750 and 0-1000-lb. ranges. It weighs 1½ lbs. All sizes of each model are supplied with attachment shackles and carrying cases. All are designed to withstand 100% overload or a full shock recoil through disengagement of mechanism. Several are special-purpose instruments, with special accessories.—*W. C. Dillon & Co., Inc., 5410 W. Harrison St., Chicago, Ill.*

Automatic Control for Sodium Lights

Photoelectric control is embodied in each individual sodium luminaire of new system designed to minimize accident rate at underpasses, etc., where the "dangerous twi-



light" is the principal hazard. The electric eye and associated equipment to operate the lamp automatically from an ordinary 120-volt 60-cycle power supply are located in a compartment on the back, or pole side, of the luminaire. The control is preadjusted at the factory for "excellent sensitivity" and is compensated against flashes of light (lightning, for example) that might affect the operation.—*General Electric Co., Schenectady, N. Y.*

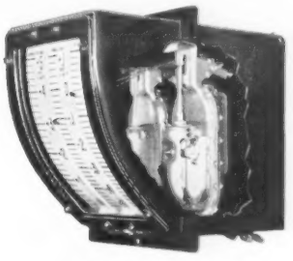
BAILEY METERS

METERS and CONTROL *for Boiler Room Service . . .*

Boiler Meters Reduce fuel costs, lessen maintenance and outage, lower standby costs, and add capacity. They indicate, record and integrate Steam Flow from the boiler, record Air Flow supplied for combustion and record Flue Gas Temperature.

Bailey Boiler Meter

Multi-Pointer Gages for indicating drafts, pressures, differentials are available with any number of pointers from one to twelve. They are actuated by sturdy yet sensitive diaphragm units.



Multi-Pointer Gage

Flow Meters. For indicating, recording and integrating the flow of steam, feed water, compressed air and other fluids.

Coal Meter

Granular Material Meters For accurately measuring the flow of coal or other granular materials in gravity chutes from overhead bunkers. The total quantity of granular material is shown on a large illuminated counter which may be easily read at a distance of 50 feet.

Control Systems Make possible the everyday operation of equipment for steam generation and utilization at test efficiencies. They are applied to the control of combustion, feed water, superheat, desuperheat and other factors.

Complete Information on any of the above Bailey products will be gladly furnished upon request.

G-14

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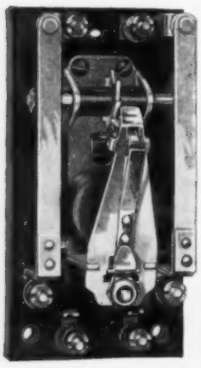
1041 Ivanhoe Rd., Cleveland, Ohio
BAILEY METER COMPANY LTD., MONTREAL

Midget Ratchet Relay

New "Type CX2600 Ratchet Relay" is said to combine small physical size with dependable performance in opening and closing a circuit over a single line. It has two independent poles and, by factory adjustment of its cams, may be made single-pole double-break single-throw; double-pole single-break single-throw; or single-pole single-break double-throw. Units are available for both intermittent and continuous duty. Base size is 3-13/16" × 2", the relay being designed for front-connected vertical mounting. Contact rating for non-inductive load is 110 volts, 6 amps., or 220 volts, 3 amps. a.c.; or 115 volts, 1 amp. d.c. Coils are available from 6 to 220 a-c. volts, at approximately 4 watts; or 2 to 230 d-c. volts, at approx. 2 watts. D-c. voltages above 90 require a series resistor in the coil circuit. — *Struthers Dunn, Inc., 1335 Cherry St., Philadelphia, Pa.*



Hand Tachometers

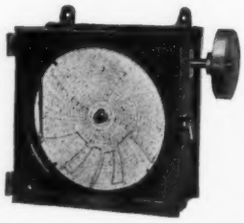
Four new models of centrifugal tachometers are announced, each a two-scale five-range instrument (range selection by rotating barrel head). Open graduations are an

inherent characteristic, resulting from each range spanning only a 4:1 range, as well as from 20% to 33⅓% overlaps. Extreme limits, between low end of lowest range and upper end of highest range, for the four models, are as follows:

No.	1	2	3	4
Lowest	30	45	60	120
Highest	12,000	18,000	24,000	48,000

Instruments are designed for right- or left-hand rotation, are unaffected by magnetic or electrical influences, moisture or temperature changes. Mechanism transmitting movement of centrifugal element to the dial contains miniature ball bearings. The vane for a periodic damping runs in copper-beryl bearings. Numerous oil holes permit the lubrication of torsion mechanism and gearing. Bearings of transmission mechanism are factory oiled and do not require further attention. Each tachometer is individually calibrated and checked up to maximum speed. Seeing "Switzerland" on dial, *Instruments* inquired as to replenishment of stocks in New York; answer was "by weekly sailings from Lisbon."—*Coats Machine Tool Co., Inc., 110 W. 40th St., New York City.*

Amthor

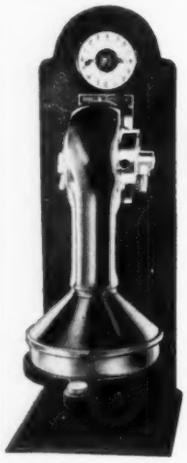


Operation Speed Recorder 8" Chart 12 or 24 hr.

Built for severe service. Users report 10, 12 or more years of trouble-free life. Powerful centrifugal speed-measuring element stays calibrated. Non-spill reservoir pen. Special chart paper. Rugged clock movement. Ideal for analysis of new Defense jobs.

Immediate and intelligent attention will be given to your inquiries on all industrial speed measurement problems. Drop us a line today.

Amthor Testing Instrument Co., Inc.
49a Van Sinderen Ave. Brooklyn, N. Y.



★ **Moisture Teller** ★

Rapid and accurate moisture test in percentage by drying. Drying temperature controlled by thermostat. Ideal for plant moisture control or laboratory moisture determinations.

Time required to dry the majority of materials is one minute.

Suitable for granular—fibrous—crystaline materials in industries such as:

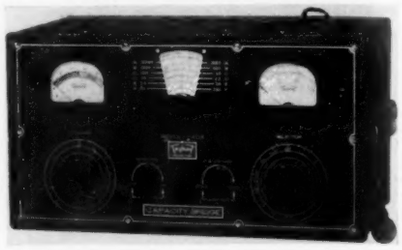
Sand—Textile—Tobacco
Ceramic—Rubber—Food
Wood—Mining—Leather

Write for Literature

Harry W. Dietert Co.
9330-C Roselawn Avenue
Detroit, Michigan

Capacity Bridge

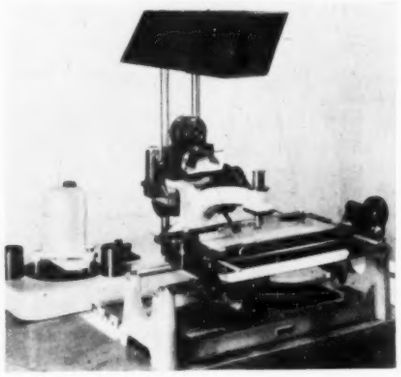
New "Model 1640 Laboratory Condenser Bridge" checks the capacity, at 60 cycles, of all condensers — paper, electrolytic or mica—from 0.00025 to 250 microfarads. It



is said to permit making rapid but conclusive tests for shorts, opens, leakage and breakdown. Two 3" "Red Dot" instruments are incorporated: one has a GOOD-BAD scale for leakage of electrolytics from 2 to 250 mfd., based on 0.2 ma. per mfd. at rated voltage. Control permits other ratings as well as direct readings in milliamps. For capacitor leakage measurements the voltmeter and milliammeter are in the circuit at the same time. Direct current for checking leakages up to 600 volts variable. Tester operates from 110 volts, 60 cycles a.c.—*The Triplett Electrical Instrument Co., Bluffton, Ohio.*

Galvanometer Reader Unit

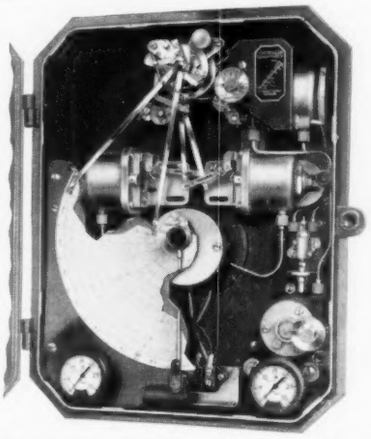
New "Galvanometer Reader Unit" projects a moving galvanometer scale across a fixed index on a translucent screen. The image of the scale moves *vertically*, while the cross-



hair is located at a convenient height for observation, so that the eye does not have to follow a moving spot. It is said that readings can be made more conveniently and rapidly and with considerably less fatigue, particularly over a continuous set of measurements, than with the normal method of observation. (Illustration shows the new device with a Hilger Non-Recording Microphotometer.) Unit comprises a fine-engraved transparent scale, illuminated by a lamp and specially-computed condenser system, which is reflected from the galvanometer mirror and then projected greatly magnified through a lens, right-angle prism, and front-surface mirror onto the translucent screen bearing the cross-hair. The screen is so enclosed that it can be read in a well-lighted room. The galvanometer, of the taut-suspension type relatively insensitive to vibration, is supported on a cushioned vibration-free mount. All parts are assembled on a 12" × 24" cast-iron base. The characteristics of the galvanometer and projection system are such as to give a sensitivity of 0.0005 microampere per millimeter. The internal resistance is about 450 ohms and the full period two seconds.—*Jarrell-Ash Co., 165 Newbury St., Boston, Mass.*

Direct-set Ratio Controller

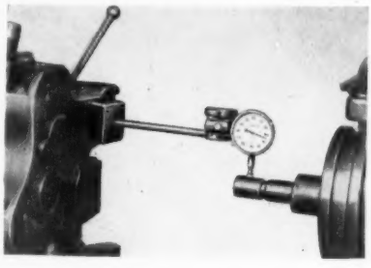
New Direct-setting Ratio Controller is described as a highly adaptable, easily-convertible instrument for applications where a temperature, pressure, rate of flow or liquid level must be controlled in a desired



ratio or differential to another related variable. With it, the ratio is changed by a simple screwdriver adjustment directly on a calibrated dial throughout the range of 0:1 to 3:1, direct or inverse. It is unnecessary to disturb the processing or remove the chart plate while making ratio adjustments. Ratio Controller has two measuring systems: (1) the adjusting system, which indicates or records only; (2) the controlling system, which may either indicate or record. The adjusting system resets the control point of the controlling system through a linkage arrangement according to a predetermined ratio. The action of the controlling system is the same as that of maker's "120R Series Fulscopes" and may be used as a single-duty bi-recording controller when the ratio setting is zero. Both indicating and recording models of the Ratio Controller are available, with choice of: (1) Fixed High Sensitivity, (2) Adjustable Sensitivity, (3) Adjustable Sensitivity with Automatic Reset, (4) Adjustable Sensitivity with Pre-Act, and (5) Adjustable Sensitivity with Automatic Reset and Pre-Act.—*Taylor Instrument Companies, Rochester, N. Y.*

Magnetic Indicator Base

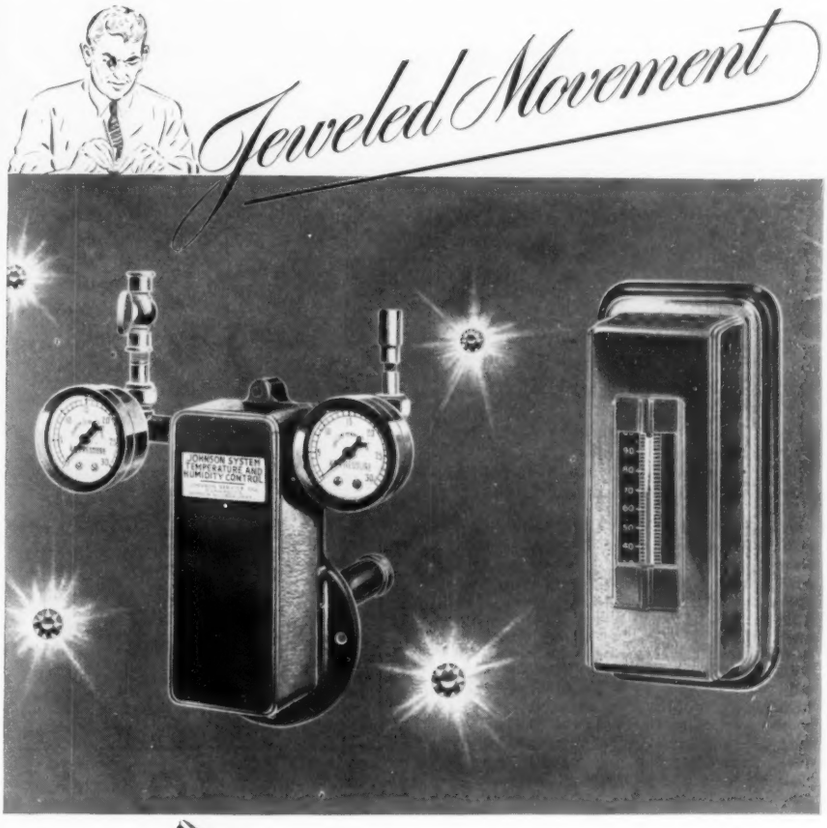
New "Magnetic Indicator Base" for dial test indicators, employs a ring type permanent magnet and a center post as its magnetic poles. Space between the poles is filled



with cement and the entire base ground flat. New device simplifies the work and reduces the time required to set an indicator into position, is especially useful in difficult set-ups where special clamps or fixtures would be necessary. In case the work jams, the base will be pushed out of position before ruining the indicators. Device is secured in any position by simply placing it against an iron or steel surface. It can be used on round columns by inserting two wedges, any scraps of steel serving as wedges. Magnet is of Almico, a permanent-material which will support over fifty times its own weight, does not weaken over a period of years, and withstands shocks and vibrations. — *Mellaphone Corp., Rochester, N. Y.*

G-R-A-D-U-A-L CONTROL!

JOHNSON'S SMOOTH-OPERATING



FOR LONG-TIME PRECISION

Johnson uses *sapphire jewels* in the bearings of thermostats and humidostats! Accurate performance depends upon smooth, easy movement of the levers in such instruments. Friction must be held to a minimum. Consequently, Johnson's strict standards demand hardened steel pivots, operating against precious stones. This means less friction than any other combination of bearing materials. Such care may seem like needless refinement. But Johnson is not satisfied merely to produce thermostats and humidostats that are just good enough to "get by."

The recognized Johnson standard of excellence is "precision instruments for precise control" of comfort air conditioning and industrial processing. Here, again, is evidence of the extreme care and precision that characterizes the design and manufacture of Johnson's modern apparatus. Send for bulletins which describe the smooth-operating jewelled movement instruments and other interesting Johnson equipment.

JOHNSON CONTROL: *The "BRAIN" of the Air Conditioning System*

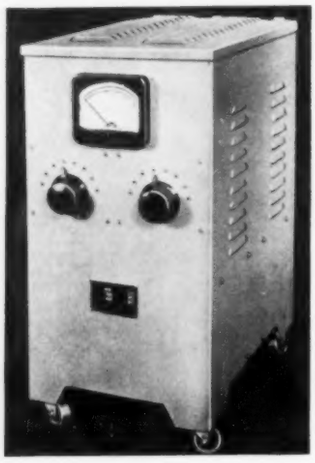
JOHNSON

Automatic TEMPERATURE AND AIR CONDITIONING Control

JOHNSON SERVICE COMPANY, MILWAUKEE, WIS. & BRANCHES IN PRINCIPAL CITIES

Rectifier for Production Testing

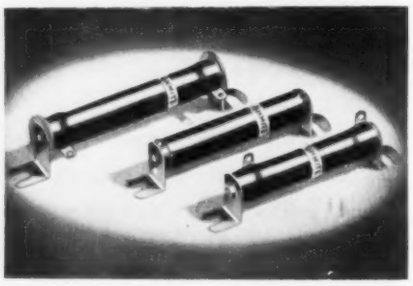
New "Model SP-60 Rectifier" has been designed to produce direct current and two-phase a.c. from standard 3-phase power lines. A Scott T-connected transformer con-



verts the 3-phase a.c. into 2-phase a.c. This is available at either 110 volts or 220 volts from the proper connections on the terminal board, providing current for 2-phase motor operation. The 2-phase is rectified also into d.c. in a full-wave circuit using four 15-amp. tubes. This circuit arrangement is said to provide a maximum amount of d-c. power with a minimum number of tubes. D-c. output voltage may be adjusted up to 250 by turning the controls on the front panel. Direct current up to 60 amps (18 hp. max.) may be obtained for production testing or operating all types of d-c. equipment. It is claimed that high efficiency, excellent voltage regulation, and long tube life are obtained by the use of mercury vapor tubes. There are no moving parts. Unit is housed in a ventilated steel case, 12" × 18" × 21". —*Mellaphone Corporation, Rochester, N. Y.*

"Live-bracket" and "Dead-bracket" Resistors

For special applications, maker's wire-wound vitreous-enameled resistors are available in "live bracket" and "dead bracket" types. The former have flexible leads con-



nected to tin-plated brass brackets, are designed for mounting and making electrical connection by bolting the slotted brackets to panel terminals. The "dead bracket" resistors are mounted by bolting to the brackets. Electrical connections are made separately to the lugs. Leakage distance from lug to bracket can be regulated by the use of mica washers or by having the lugs located as far in as required. Both types are suitable for signal circuits, appliance controls, storage battery charging, switchboards, etc. They are available in a wide range of core sizes with diameters from 9/16" to 2½". —*Ohmite Manufacturing Co., 4835 Flournoy St., Chicago, Ill.*

Speed - - -

DIRECT READING INDICATORS

Centrifugal Type

Portable and Stationary
Indicating Speed and Total Run.
Flexible Shaft, Belt, or Electric
Drives for Remote Indicating.

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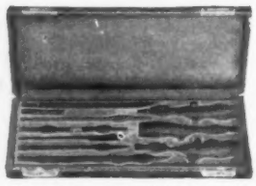

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LEATHER COVERED AND HARDWOOD FINISHED CASES FOR PRECISION TOOLS, GAUGES, AND INSTRUMENTS OF ALL KINDS.

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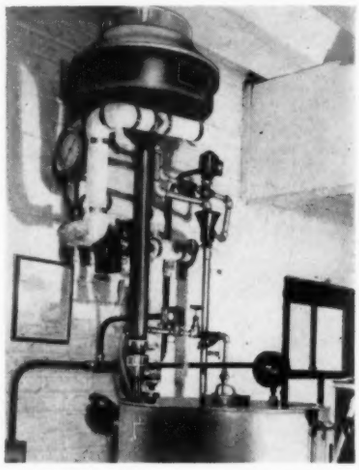
Prices furnished on request

RUECKERT MANUFACTURING COMPANY
69 SPRAGUE ST.
PROVIDENCE, RHODE ISLAND

Automatically-controlled Laboratory Water Still

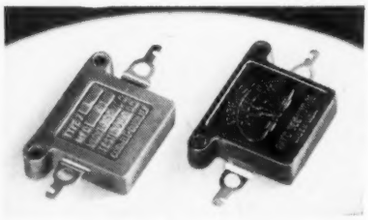
New "Triple-O" is a 3-gal. capacity, electrically-heated water still of the general type described in *Instruments*, Aug. 1940, page 202; but with complete automatic controls which start and stop the still and



maintain a fixed level of water in a storage tank; also, after each cycle, automatically flush out impurities from the boiling chamber. Design is such that formations of scale may readily and thoroughly be cleaned. Condenser tubes and other parts coming into contact with distillate are heavily tinned. Heating element has built-in dual-purpose thermal safety switch and combined low-water cut-off, is said to be practically immune to burn-out under all conditions of service. It is stated that this still will produce distilled water of purity better than U.S. Pharmacopeia specifications — suitable for exacting research purposes; that cost of operation is only a few cents per gallon of distillate and that particularly rugged construction makes these stills practically fool-proof and immune to damage.—*F. J. Stokes Machine Co., 5820 Tabor Road, Philadelphia, Pa.*

Bakelite Mica-dielectric Capacitors

New "Type 7" is a molded Bakelite mica-dielectric capacitor, similar to existing Type 4 but with wider spacing between the insulated mounting holes to meet the 1½"



standard. Standard units are available in capacities beginning at 0.00005 mfd. and up to 0.03 for those rated at 600 volts (d.c. working), 0.01 for the 1200-volt rating, and 0.003 for the 2500-volt rating. Standard tolerance in capacity ratings is ± 10%. Insulation resistance is 20,000 megohms. On each unit is clearly stamped the values of capacity and voltages. Special features required can be incorporated on special order. Capacitors can be supplied molded in low-loss Bakelite (insulation resistance 40,000 megohms) with salt-water immersion seal against humidity; or temperature aged—multi-cycle for stabilizing capacity over extremely wide temperature changes (—40°C. to 70°C.).—*Cornell-Dubilier Electric Corp., South Plainfield, N. J.*

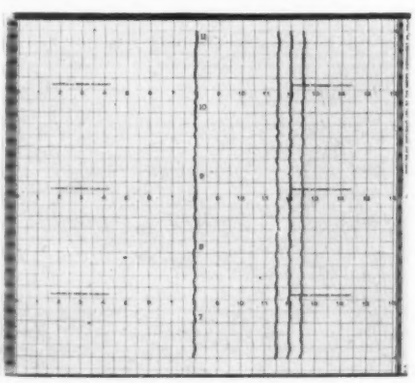
Can-filling Machine "Tipper" Temperature Control

A temperature control system is announced for "tippers" on automatic can filling machines. These have heretofore been manually controlled, temperature being de-

pendent only on judgment of operator. They are fed from reels of solder wire. New system has its primary element forming a part of the tipper assembly. Thermocouple recommended is an I-C pencil type, ⅛" O.D., extending through tipper shaft so that its measuring junction almost touches center of soldering head. Tipper fuel being gas, control is obtained by a by-passed solenoid valve commanded by the pyrometer controller. Initial adjustment of by-pass is made manually. Entire system is available as a millivoltmeter type or as a potentiometer type, calibrated for I-C couple, range 0-1000°F.—*The Brown Instrument Co., 4482 Wayne Ave., Philadelphia, Pa.*

Recording Potentiometer for Glass Lehrs

Announcement is made of a specially-developed Multi-Record Potentiometer for Glass Lehr Temperatures and Speed. Records of the glass lehr belt speed and the



temperatures of the lehr heating zones are combined on one chart. Instrument can be furnished with one speed record and one, two, three or five temperature records. Contrasting colors of the different record lines make it easy to distinguish the various thermocouples and the lehr speed record. A continuous record of the glass annealing process is furnished, and it is said that correct lehr conditions can be maintained at all times, eliminating spoiled ware and assuring increased "pack." Standard range is 0-1600°F.; standard calibration is for I-C. couple; standard speed record range 0-16 r.p.m.—*The Brown Instrument Co., Wayne & Roberts Avenues, Philadelphia, Pa.*

A LARGE OIL REFINERY ASKS FOR ANOTHER **PORTABLE PYROMETER**

for a range of —200°C. to +40°C. calibrated for copper constantan thermocouples, a duplicate of an instrument previously furnished.

Our files show many duplicate orders for PYROMETERS in ranges up to 3000°F. from satisfied customers. Ruggedness in construction, accuracy of indication, and long life give results that mean repeat orders. Our instruments will satisfy you too.

CHARLES ENGELHARD, INC.

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MERCURY DIAL THERMOMETERS

1—VERY SENSITIVE
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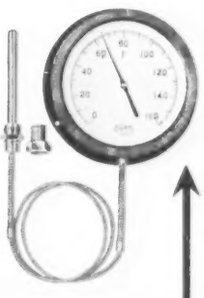
3—STURDY BUILT
4—EASY TO READ
5—ALL RANGES



Palmer Dial Thermometer Installations have proven to be very satisfactory because of their accuracy and sturdy construction. Stainless-steel flexible tubing connection and bulb are standard without extra charge. Furnished with plain bulb, union connection, separable-socket and flange connection. Ranges: —40 +1000° F. (or 550° C.). Built by craftsmen who know how to make good thermometers. (Write for Bulletin No. 1500.)

THE PALMER CO. Mfgrs.

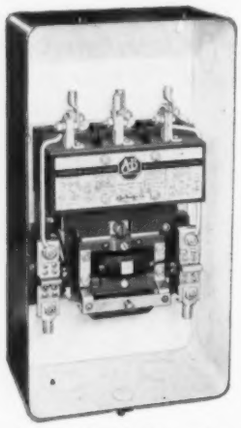
THERMOMETER: Recording, Industrial, Laboratory and Dial

2511 NORWOOD AVE., CINCINNATI, NORWOOD, OHIO

Canadian Plant: King & George Sts., Toronto

Solenoid Starter

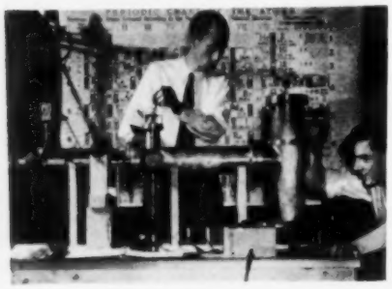
Said to meet the demand for a larger starter with the solenoid switch structure, new "Size 4, Bulletin 709" solenoid starter has a max. hp. rating of 50 hp., 220 volts



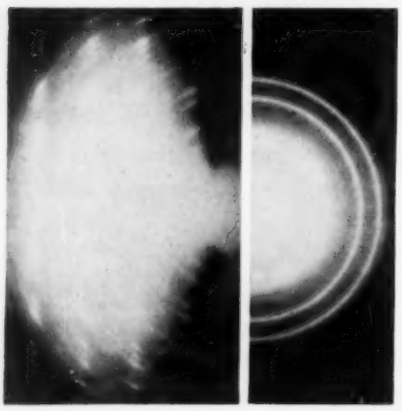
and 100 hp., 440-550-600 volts. Double-break, cadmium silver contacts are totally encased in an arc hood, each pole of the switch having its individual arc chamber. Hence, these starters can be closely grouped without danger of flash-over between switches. Because of solenoid design, size has been greatly reduced compared with that of the clapper-type starter which is replaced. Arc-interrupting capacity is high: currents of at least ten times the maximum horsepower rating are easily interrupted it is said. Switch has only one moving part. Self-insulated metal base plate may be mounted on any metal surface without extra insulation.—*Allen-Bradley Co., 1311 S. First St., Milwaukee, Wis.*

Electronic Vacuum Camera

An electronic vacuum camera that photographs the crystalline structure of substances millionths of an inch thick is being used to study deposits on the surfaces of

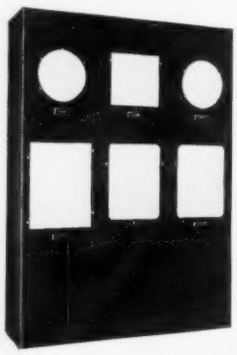


metals, e.g., tarnish, polish, lubr'cants such as grease and oil and the first stages of corrosion. Camera proper consists of an evacuated brass tube about 3½ ft. long and a focusing magnet. A 40,000-volt electronic beam enters one end of the tube, is focused by means of the magnet upon the material suspended in the middle of the tube, diffracts, and produces a picture upon a lantern slide at other end of tube. Specimen is suspended in such a way that it can be raised or lowered or tilted at any angle to the beam. Electron beam is reflected by, or transmitted through, the material and a diffraction pattern produced upon the lantern slide. From spacing and intensity of circles, or spots, of pattern, it is possible to determine the crystalline structure. Example, layers of atoms in table salt are spaced one microinch apart, yet a typical electronic picture shows a circle 1" in diameter.—*General Electric Co., Schenectady, N. Y.*



COMMON SALT GOLD

FALSTROM



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● FOR AIRCRAFT TEST WORK

Trimount Well Type Manometers have been accepted because of their wide range and flexibility in performing all tests which require great accuracy, for testing aircraft equipment. - - Send us your inquiry for manometers and catalog B-2.

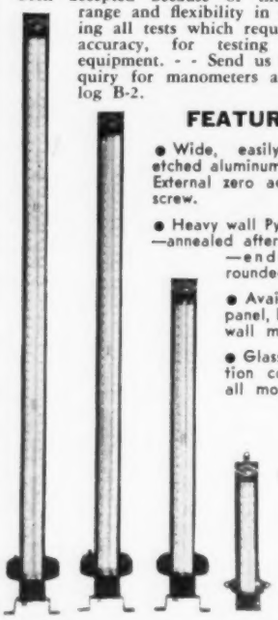
FEATURES

● Wide, easily visible etched aluminum scales—External zero adjustment screw.

● Heavy wall Pyrex tubes—annealed after forming—ends flame rounded.

● Available for panel, bench or wall mounting.

● Glass protection covers on all models.

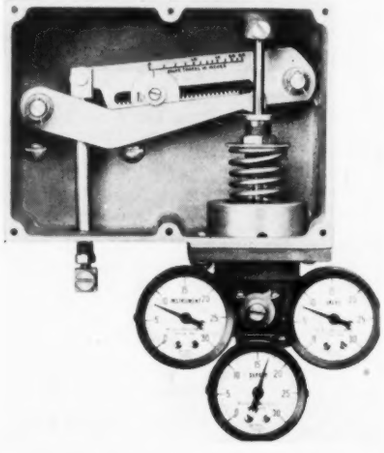


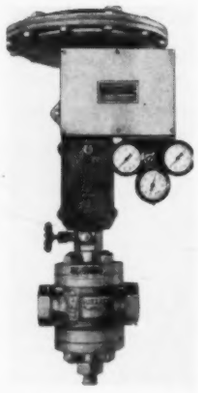
TRIMOUNT INSTRUMENT CO.
37 W. VAN BUREN ST. CHICAGO, ILL.

TRIMOUNT MANOMETERS

Valve Positioner

New valve positioner for diaphragm valves provides for the optional use of a by-pass valve which is made as an interchangeable part of the unit. Emphasis has been made, it is said, to provide a sturdy construction similar to that of the valve with which it is used, to meet actual operating requirements. Heavy calibrated loading spring, in addition to operating the pilot bellows, always acts in the same direction to take up any back-lash in the lever connections. Adjustments for valve strokes of ½" to 2½" and for setting zero, are accessible, may be made without interrupting the controlled process. By turning the by-pass from "Positioner" to "Instrument" the positioner may be completely removed without upsetting the service. Design is such that a linear relationship always exists between instrument air pressure and actual motion of valve. Bellows and stainless steel pilot are a self-contained unit; no levers to introduce friction and cause hysteresis errors. It is said that tests have shown a sensitivity of 0.2% for full-scale instrument pressure change. Speed of operation has been found to be approximately 11 seconds for full travel on an average 1" stroke valve. Air consumption is less than one cubic foot of free air per minute at mid-stroke, and zero at either end of the valve travel since the pilot is closed at both limits.—*Moore Products Co., 3629 N. Lawrence St., Philadelphia, Pa.*





PORTABLE
WHEATSTONE BRIDGE

A high grade instrument for measuring resistances from a fraction of an ohm to 10 megohms. Contains a 4-dial rheostat, ratio dial, galvanometer and battery, all enclosed in a substantial walnut case. Nine coils per dial. Accuracy .1%. Built to endure.

Cat. No. 1050—Portable Wheatstone Bridge with Murray and Varley Loops...$110.00

Cat. No. 1052—Portable Wheatstone Bridge without Murray and Varley Loops.$90.00

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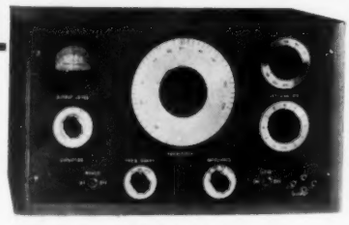
Electrical Instrument Makers

Ridge Ave. at 35th St. Philadelphia, Pa.

Time Saving Performance
with
HEWLETT-PACKARD
Laboratory Instruments



Model 205A

Audio Signal Generator

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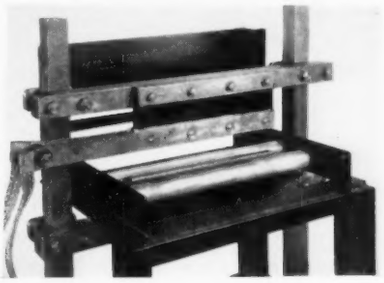

said to combine rugged construction with high sensitivity and stability; and to require negligible maintenance. Standard model, illustrated, is designed to enclose a conveyor belt carrying the product to be inspected. Standard opening is 18" wide by 2" high, and finder is designed for conveyor speeds between 20 and 100 ft./min. (other openings and speeds available). Iron pieces the size of cigar box brads are easily detected. Finder output is fed to a power relay which may be used to stop conveyor, to flash a light or sound an alarm. Piece containing tramp iron may be marked automatically if desired. In addition to the inspection of rubber, plastics, etc., device is also effective for finding ferrite inclusions in stainless steel strip, and as a concealed weapon detector.—*Andrews & Perillo Inc., 39-30 Crescent St., Long Island City, N. Y.*

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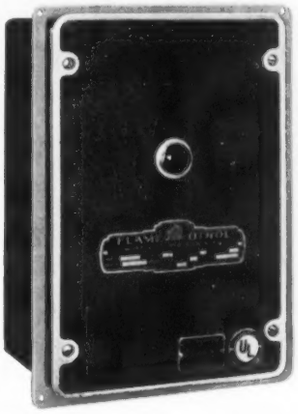

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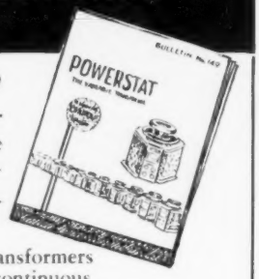

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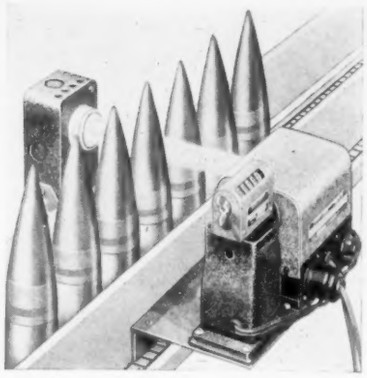

be difficult or impossible to secure it mechanically. Counter need not be installed at the point of contact. Productimeter may be placed in an office; or, two counters operated by a single photoelectric control may be used: one at the point of application, the other in an office. Counter has a guaranteed speed of 500 counts per minute, and is available in 5 or 6-figures capacity. The illustration shows the application of maker's photoelectric equipment on a conveyor. Set is composed of three units: magnetic counter, photoelectric relay; beam projector or light source. It operates from a lighting circuit of 110, 6, or 220 volts, 60 cycles, a.c.—*Durant Mfg. Co., 1914 N. Buffum St., Milwaukee, Wis.*

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2-position toggle switches and a 3-position rotary switch then permit selection of the type of measurement and range desired. Eighteen measurement ranges. Curves and data supplied with instrument permit rapid conversion for different values of voltage and power factor. Tester permits also making power measurements of motors up to several horsepower. Overall dimensions 5⅞" × 3¼" × 2".—*Radio City Products Co., 88 Park Pl., New York City.*

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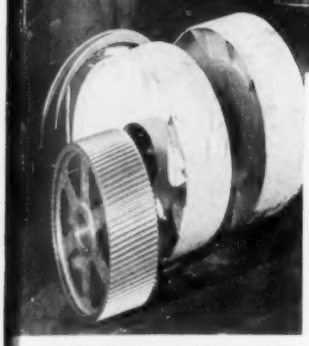


PICTORIAL FEATURE

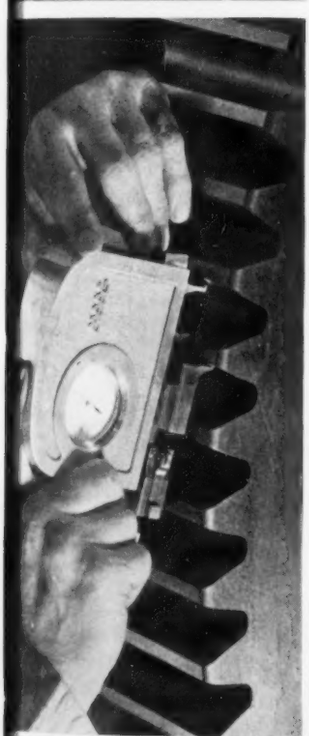
Instrumentation

AT THE

Nuttall GEAR Works

of Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

FREQUENTLY eclipsed by spectacular power or process control panels, the form of instrumentation known as Shop Measurements is coming into its own as it answers the cry for "Speed, Speed and more Speed." Here in Pittsburgh is a good example at the Nuttall Gear Works: instruments ranging from simple gages to control systems; and uses ranging from intermittent single measurements to continuous autographic tests and automatic control.



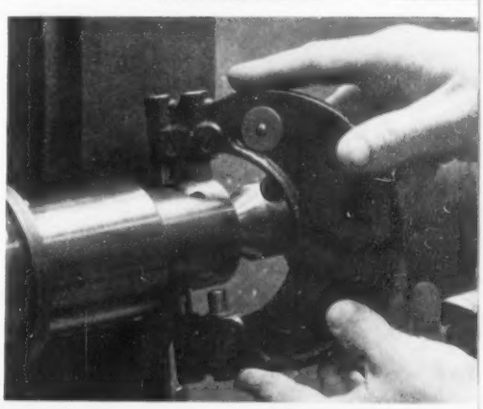
Top—Lots of instruments in this aisle . . . but they only show in close-ups.

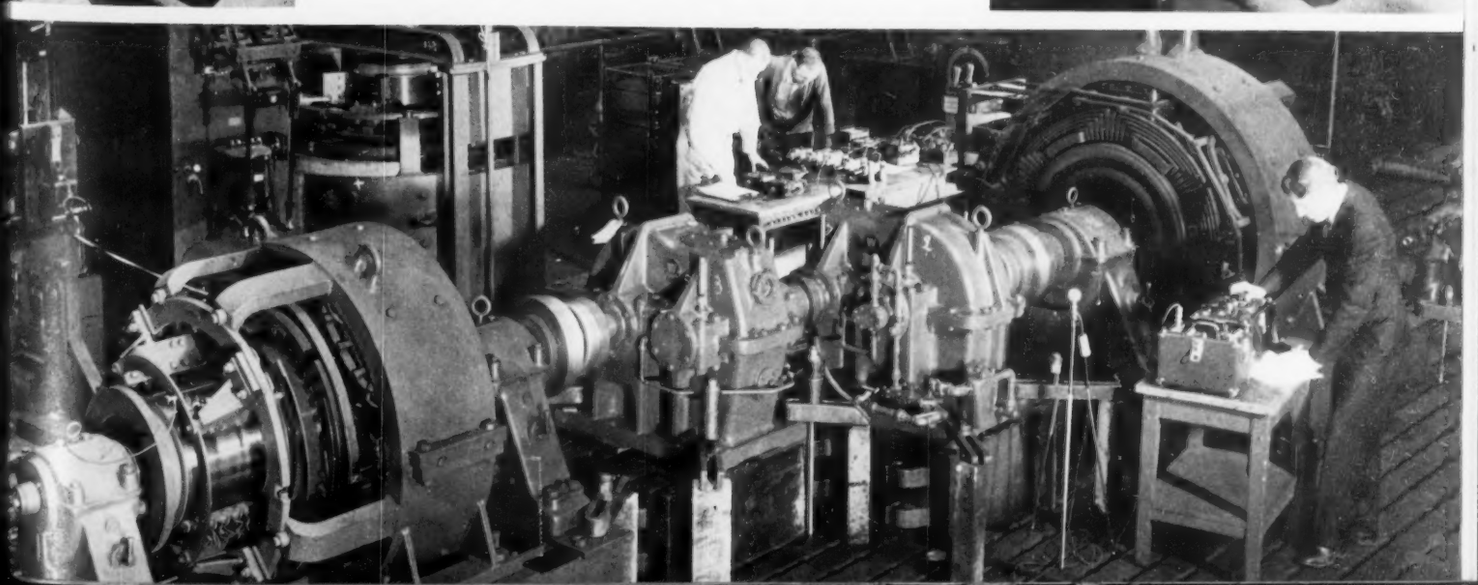
Left—Measuring normal pitch to 0.00005" at any angle between base and tip.

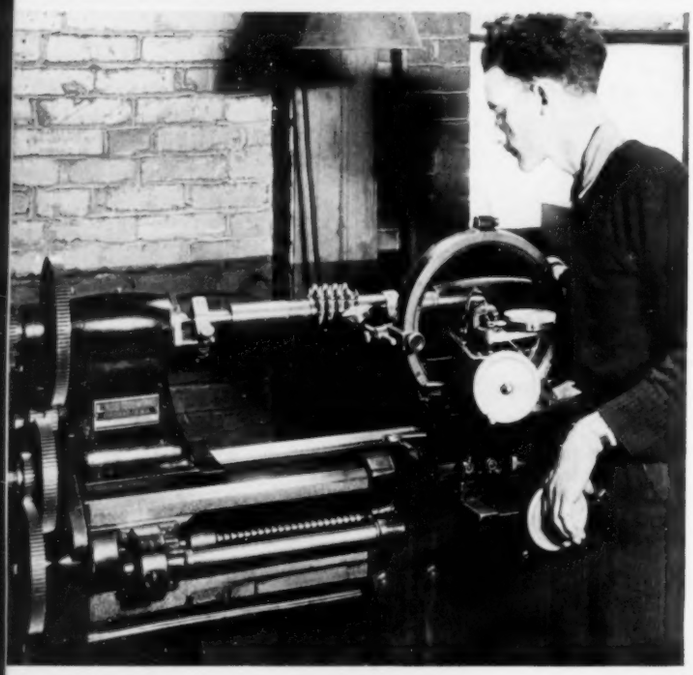
Right (upper)—"Miking the teeth" while hobbing a locomotive drive gear.

Right (lower)—Snap gage check of work on a grinder. All snap gages are set and sealed in the tool room.

Bottom—Testing two speed reducers simultaneously, for noise level, temperature, efficiency and lubrication.





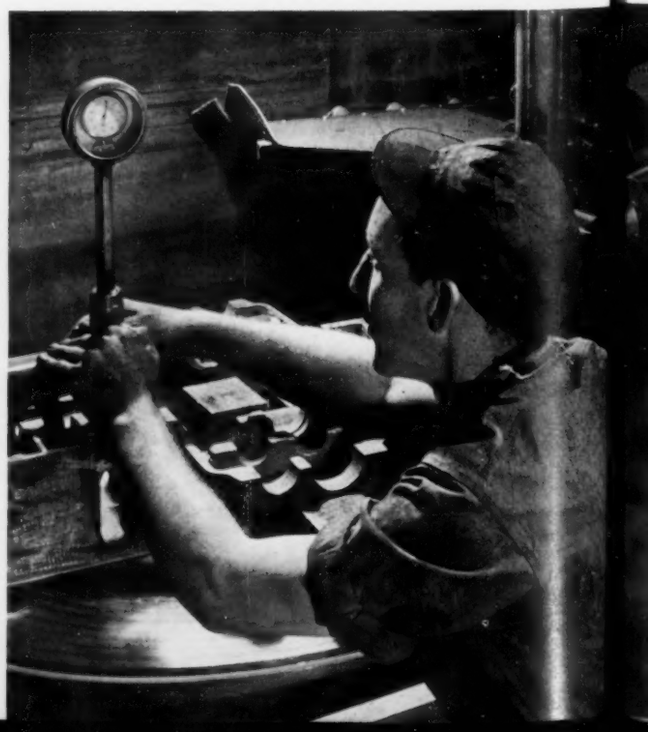


Top (left and right)—Ammeters provide a constant check on the power consumption of machine tools and hence on the efficiency of the operation, particularly on the condition of the work-tool, whether it be an abrasive wheel in a grinder (left) or a cutting tool in a lathe (right). And that's only the beginning of the story disclosed by ammeters.

Upper left—All new hobs are checked in this special machine, for gash-to-gash spacing, lead, profile, and eccentricity of cutting edges, etc. The "machines" such as the one shown, really are "instruments," as are the sensitive gages.

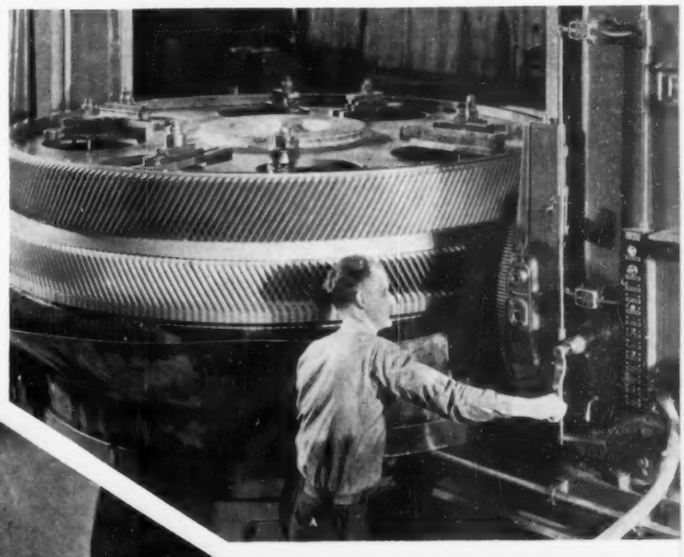
Lower left—After hobs have been checked for tolerances, each of them is checked for location in the hobbing machine. The delicate adjustments require a high grade of skill, but a special pair of dial indicators aids the machinist.

Bottom right—This dial indicator installed on a grinder is arranged to swing over the work at the operator's will—thereby serving as a height gage to indicate the amount of stock removed.



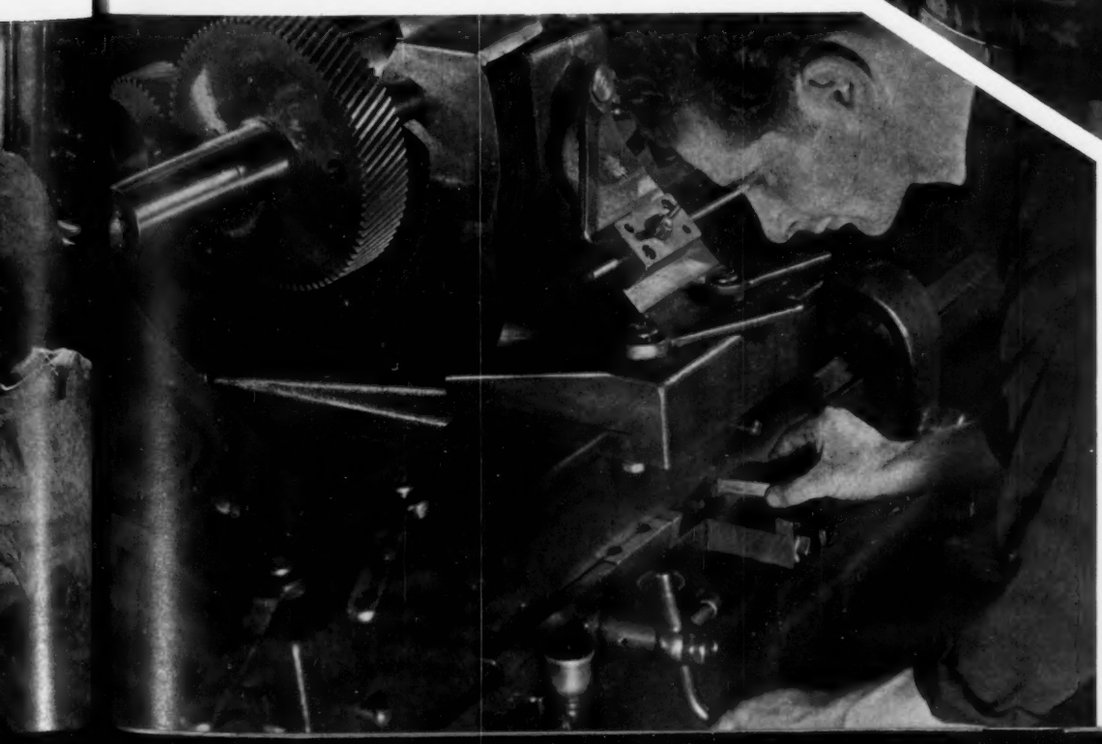
Top (left and right)—These two photographs bring out the combination of human skill and instrumental aids which make modern heat treating an art and a science. Split-second timing in multiple-quenching, calls for human skill, but complete automatic control of carburizing and tempering furnaces assures carrying out the metallurgists' specifications for temperature-time cycles.

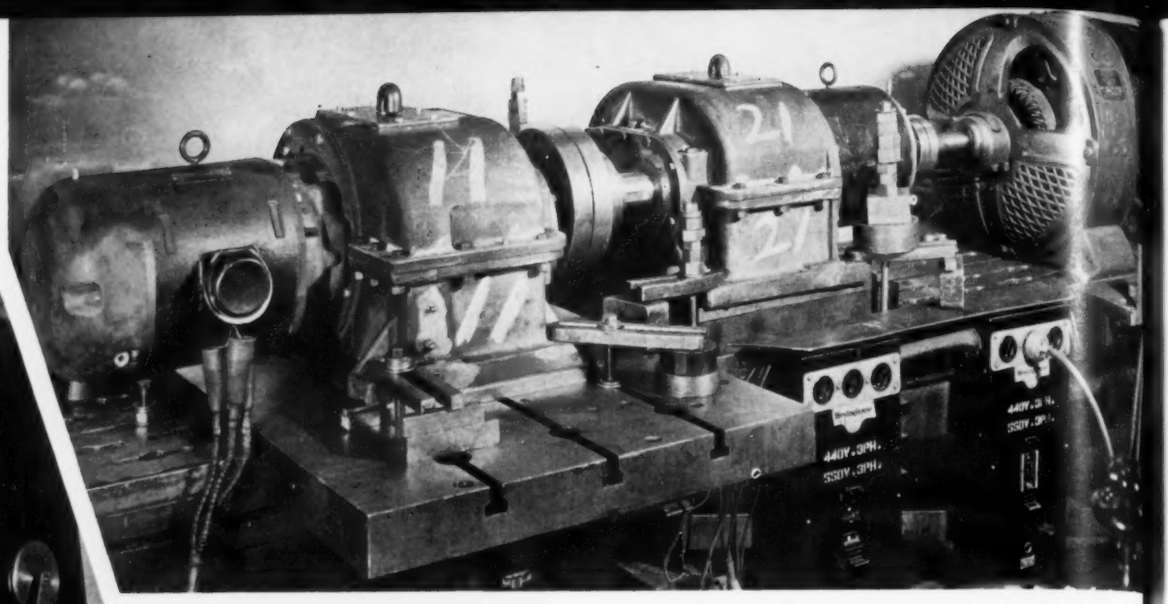
Right — Push-button remote-control and automatic limit switches, etc., are the trend in the instrumentation of machine tools—especially the giants that are required for making such gears as this one, a 102″ double helical marine gear for the biggest twin-engine Diesel drive ever built in this country.



Bottom left—An uncommon use for gage blocks is the exact control of center-to-center distance on this machine, where gears are run in at full speed.

Bottom right—The new final-finishing operation known as "shaving" follows hobbing. The machine operator "mikes" for proper tooth depth and face width, after which the machine operates automatically.

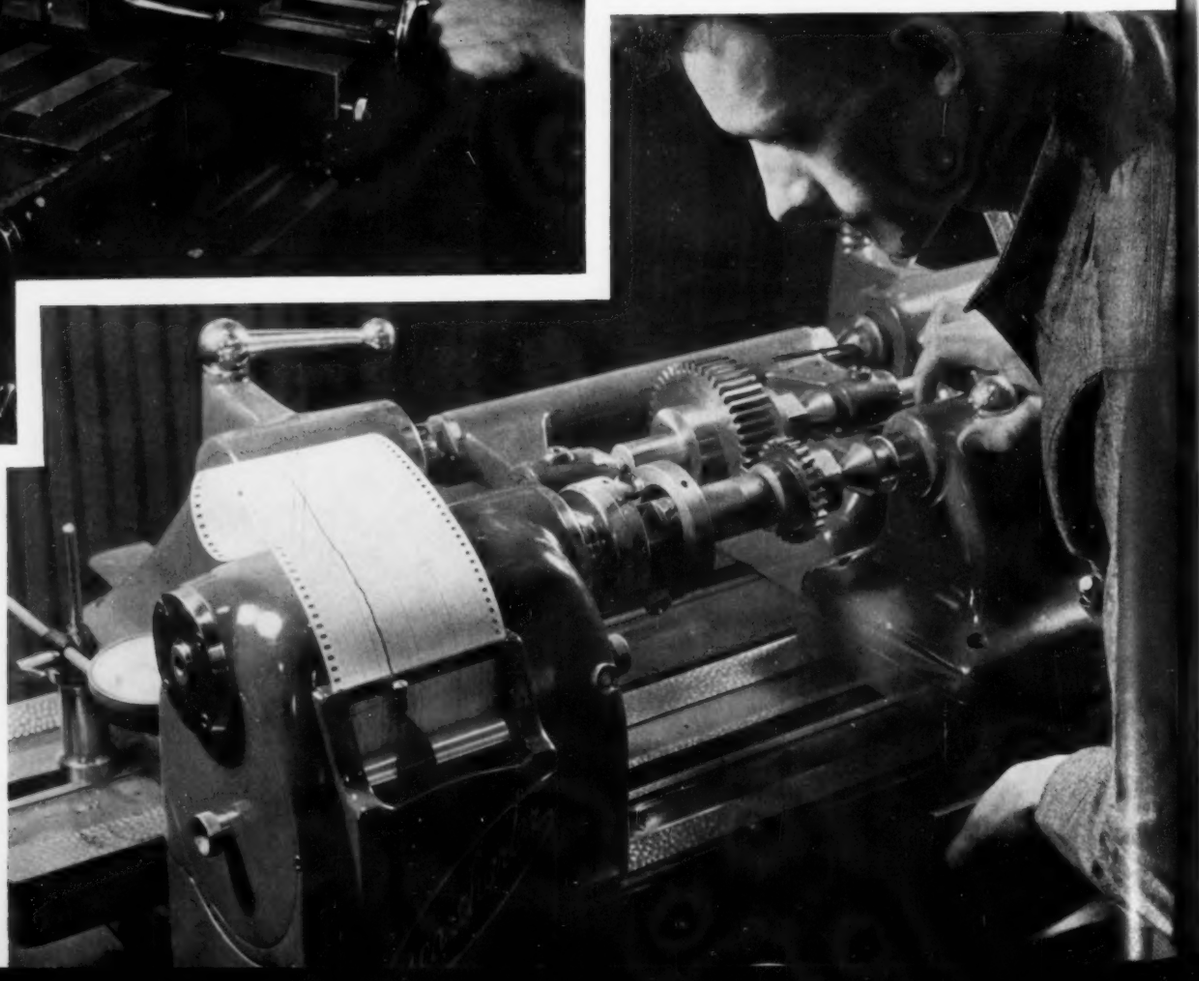




Top—Full-load test wherein the gearmotor under test drives a high-speed generator through another gearmotor used as a speed increaser. (Not shown is the array of electrical instruments.)

Left—This "machine-instrument" checks finished pinions for tooth spacing and tooth profile. One of three fingers abuts a given tooth; the second (spring-actuated) provides constant pressure; the third actuates the dial indicator. Sine bar setting is checked by gage blocks. Tooth profile tolerance is 0.0002".

Bottom — This other "machine-instrument" meshes the gear under test with a "master" and produces a chart record of its profile, concentricity and tooth spacing. "Bumps" thus located are then eliminated.



Integrator for Circular Ordinates*

By WALDO H. KLIEVER

Associate Engineer Physicist with U. S. Cotton Ginning Laboratory, Leland, Miss.

THIS integrator was designed and built at the United States Cotton Ginning and Packaging Laboratories for integrating curves from a recording wattmeter to find total power used in experimental ginning and pressing operations. The wattmeter pen moves across the chart in the arc of a circle with center at the axis of the "movement." No instrument was found on the market suitable for integrating this type of record, and since there are many recording wattmeters and other types of recording instruments in use with pens moving in circles, it is believed that this description will be of interest.

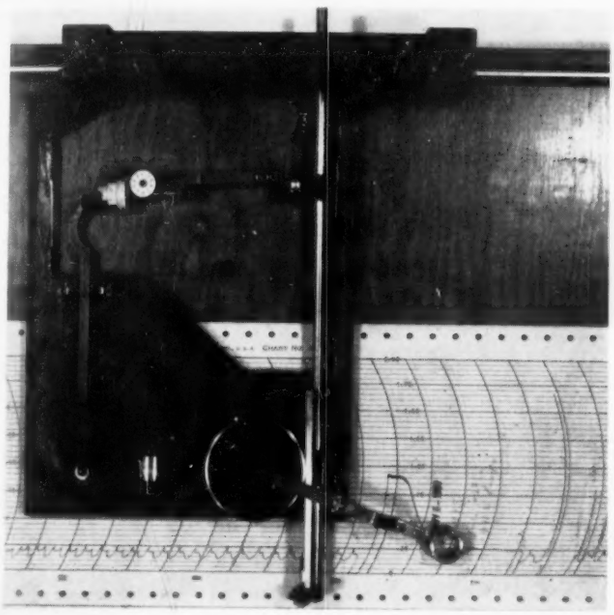


Fig. 1. Top view of integrator showing part of table and guide, and type of chart for which it was designed. (Public patent applied for.)

PRINCIPLE

It is obvious that an instrument measuring area under the curve does not give the desired result. If the rotation of the measuring element, i.e., the angle θ that the pen arm makes with its zero position, is proportional to watts or other magnitude recorded, then the integrator should give the value of $\int \theta\, dx$ where dx is the distance along the time axis of the chart. The usual type of integrator gives $\int y dx$ = area under the curve, where y is the distance straight across the chart. The problem of designing a suitable instrument using an integrating wheel is thus one of converting θ into y, or into sin ϕ where ϕ is the angle which the axis of the integrating wheel makes with its zero position or position of no rotation.

Such an integrator is illustrated in Fig. 1 and the principle of operation can be seen from the diagram, Fig. 2. Let a tracer arm have a length R equal to that of the pen-arm of the instrument which recorded the curve to be integrated. Let it be pivoted about a point O which moves along the chart parallel to the time axis in the same relative position as the pen-arm axis originally had (usually the center of the chart). Then, if the zero of the chart is taken to correspond to the position of zero angle of the tracer arm, its angle for any point on the curve will be the same as originally assumed by the recording pen arm, and this is considered as proportional to watts or other measurable.

Now let a wheel of radius r turn with the tracer arm about O and let a connecting rod slide perpendicular to the time axis tangentially against the periphery of the wheel, without slippage, i.e.—a friction drive between ring O' and rod V. Let an integrating wheel be mounted on and with axis parallel to, an arm of length a pivoted at P, and let P and O be fixed on a carriage which moves parallel to the time axis. The other end of arm a is on a slide moving with

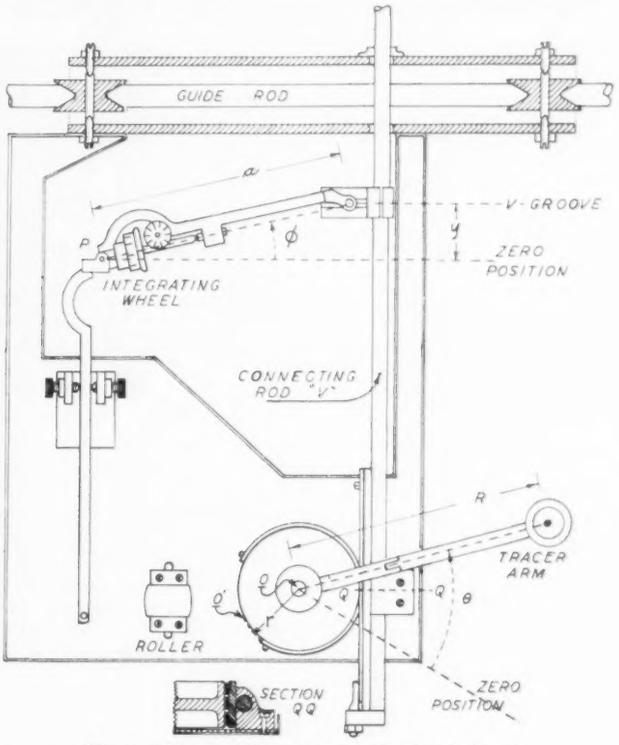


Fig. 2. Diagram of Integrator for Circular Ordinates.

the connecting rod, perpendicular to it, and so placed that when $\theta = 0$ the axis of the integrating wheel arm is parallel to the time axis. Let y be the displacement of the connecting rod from this position, and ϕ be the angle which the arm a makes with its zero position. Then it will be noted that—

$$\text{Sin } \phi = y/a = r\theta/a$$

where θ is measured in radians. The reading of the integrating wheel is proportional to sin ϕ, and therefore to θ, and to the distance traveled along time axis. By suitable adjustment of geometrical proportions as described below, the integrating wheel is easily made to read $\int \theta\, dx$ directly.

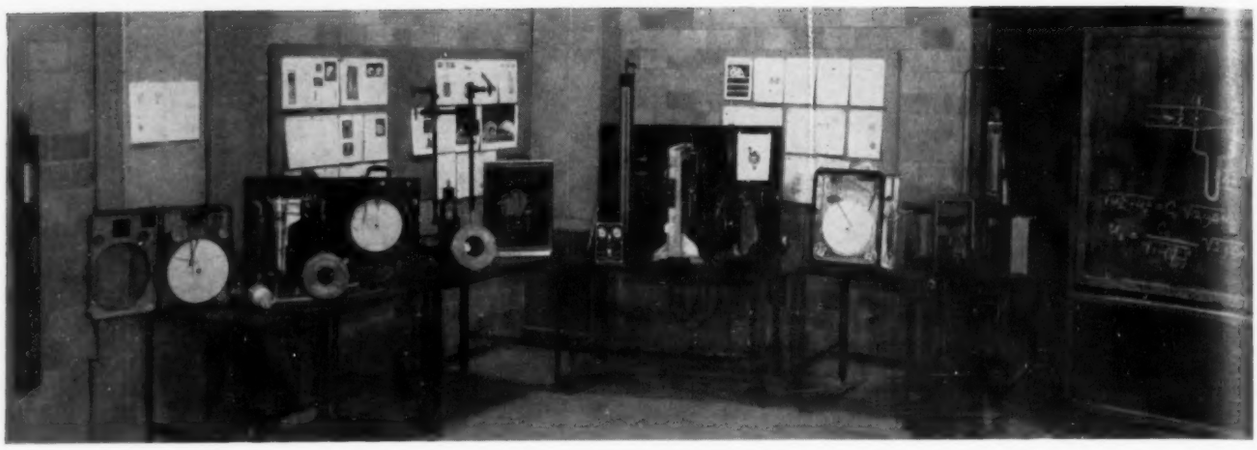
DESCRIPTION

This integrator incorporates a standard polar planimeter mounted with its polar arm fixed on a carriage. The carriage has a frame bent of 16-gage sheet metal and has two wheels of 1" diameter, with ball pivots and 60° V-grooves which guide it on a ⅜" carefully straightened drill rod securely attached to a 14" × 36" table parallel to its long dimension. The charts are held on the table with the time axis parallel to the guide. A small rounded roller carries the opposite side of the carriage.

On the carriage is mounted a bearing about which rotate together a tracer arm for the curve and a wheel or drum with cylindrical periphery. A sliding connecting rod with

Continued on Page 138

*The engineering physics phases of this work are part of a program of the Bankhead-Jones Research in Cotton Packaging under the leadership of Charles A. Bennett, Senior Mechanical Engineer, Division of Mechanical Processing of Farm Products, Bureau of Agricultural Chemistry and Engineering, United States Department of Agriculture.



A corner of the new Industrial Instrumentation Laboratory, showing equipment ready for the study of fluid metering. (Editor's Note—Our front-cover photo shows this same corner, with instructors and students at work.)

The Industrial Instrumentation Course at Case

By C. O. MILLER

Assistant Professor of Chemical Engineering, Case School of Applied Science, Cleveland, Ohio

WITH the Instrumentation course approximately two-thirds completed, the Department of Chemical Engineering at Case is truly gratified by the reception given both lectures and laboratory. To date (mid-April) the lectures have been concerned with such topics as the Principles of Automatic Control, Fundamentals of Electric and Pneumatic Control, Fluid Flow, Valve Sizing, Hydrogen Ion Measurement and Automatic Gas Analysis. Lectures are now in progress dealing with instrumentation as applied to specific industries. Included in this group are the petroleum, metallurgical, chemical, and rubber industries as well as steam generating plants installations. The final phase of the work will be concerned with such special topics as combustion control, telemetering, cycle control and piezoelectric crystals.

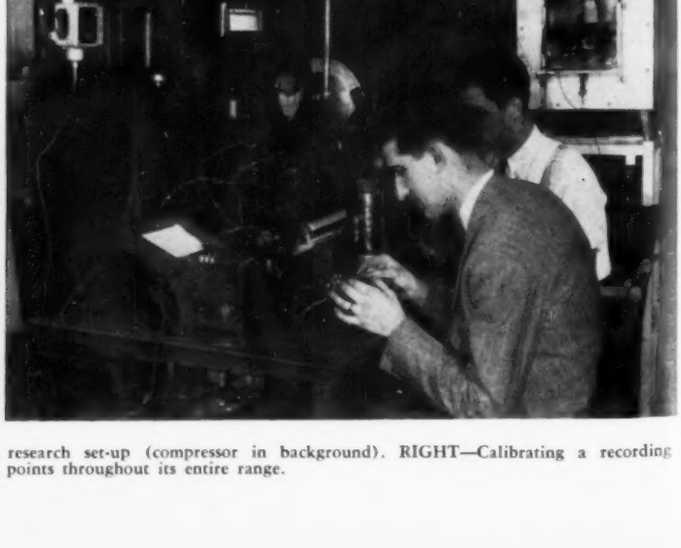
For the initial announcement and program of this course, see *Instruments*, Dec. 1940, page 396; for a brief preliminary report, see *Instruments*, Feb. 1941, page 42.

Thanks to the excellent work of Mr. W. E. Sachse of the Standard Oil Co. of Ohio and Mr. S. J. Friedman of Case, the laboratory part of the course has been kept both practical and instructive. Starting with pressure indicators and thermometers, we have considered, in order, the topics of Fluid Metering, Pneumatic Control Systems, Electric Control Systems, Fundamentals of Electricity, Thermocouples, Millivoltmeters and Potentiometers. The program for the remainder of the course includes the study of Resistance Thermometers, Optical and Radiation Pyrometers, Automatic Gas Analysis, Humidity and Space Heat Regulation, and Hydrogen Ion Measurement and Control.

The success in this undertaking is in no small measure due to the splendid coöperation given by the instrument manufacturing companies. Without their aid, the task would have indeed been difficult.

Inasmuch as it has been impossible to accommodate all of the class in the laboratory, this part of the course will be repeated during the months of June and July this summer, under the auspices of the Engineering Defense Training Program.

Having already provided a foundation, the Department of Chemical Engineering is looking forward to the establishment of a permanent instrumentation laboratory at Case.



LEFT—Checking the temperature control system on a high-pressure gas research set-up (compressor in background). RIGHT—Calibrating a recording potentiometer at various points throughout its entire range.

Time: Automatic Control's Friend and Foe

By M. F. BEHAR

1. Lags are Snags; Delays are Devils

In the preceding chapter* there were brought out a few reasons why perfect control is unattainable; the ultimate sensitivity of the primary element, the sensitiveness of the "instrument part" of a system, the further widening of the zone due to each part of the power unit and controlled valve, etc. We have seen that every stage from the primary element to the controlled valve may introduce a widening of the "overall sensitiveness" or "dead zone" or "normality."

Does this mean that a simple self-operating controller is necessarily more sensitive than a multi-stage system, merely because it is simpler? Theoretically, yes; but in actual practice—as a general rule—NO! (We must say "as a general rule" because of the enormous variety of the applications of automatic control. There are cases where only one particular type of primary element is dictated and where this type is capable of operating the particular valve required, so that it would only complicate matters to have it actuate a relay.)

One reason why perfect control is unattainable, then, is that the primary element of an actual controller cannot measure a variable with ideal accuracy. The "point" is the ideal, the "zone" is the actuality. Another reason—the one we are to deal with now—is that the "instant" is the ideal and the "interval" or "period" is the actuality. There is no such thing as a controller which instantaneously detects and measures a deviation from a setting "point" or a departure from a definite zone of normality.

Time factors create a fundamental difference between measurement and automatic control. Or, to put it more precisely, a difference between indicating and recording, and another difference between any purely measuring function and automatic control. Let us look into these time-factor differences.

For indicating, we usually have "all the time in the world." We naturally want to perform each measurement quickly because the company's time is money, but as a rule it is only when we measure variables that a delay or a lag impairs the validity of our measurements; and—also as a rule—we deliberately introduce damping in order to prevent the pointer of a sensitive indicator from oscillating so much after every rapid change that we can't read it.

In recording, of course, time is one of the coördinates wherever we use clock-driven charts. In addition to this obvious essentiality, time enters the picture in a more insidious way: delays and lags are decidedly undesirable if they are of the same order as the variations to be studied. A measuring and writing mechanism with a fixed period of one minute (example, intermittent action) cannot faithfully record fluctuations of the order of seconds. Neither can a system with a lag coefficient of one minute (example, extra-thick refractory tube around thermocouple). Fortunately, this relation between the order of the variations or fluctuations to be recorded and the order of the instrumental period or lag is so well known that it is kept in mind when we specify recorders. None of us has ever thought of using an ink-writing recorder instead of an oscillograph for recording microsecond transients! On the other hand, as in the use of indicators, we want the kind of instrumental lag called damping when we want to obtain a true record of the average, or r.m.s., or other such value rather than an oscillogram of all the successive pulses. Here, as with a damped indicator, time is the friend, rather than the foe, of reliable measurements.

In automatic control, time factors usually are foes, seldom are they friends. In order to eliminate a source of confusion, let it be said that the obviously desirable kind of instrumental lag known as measuring-element damping will not be considered. We purposely referred to it in the two preceding paragraphs in order to be able to dismiss it now. Throughout the remainder of this chapter it will be assumed that the measuring element responds to variations but not to "extremely rapid" alternations or pulsations. A familiar example is the ordinary a-c. element as distinguished from the oscillograph; another example is the "snubbed" pressure gage as distinguished from the engine indicator.

When you drive a car you are an automatic direction controller and an automatic speed controller. With regard to direction, it is obvious that if it takes half a second for what your eyes see to register in your brain cells, and another half-second for the decision, and a third half-second for your arms to start turning the wheel, you will get into plenty of accidents when driving along street-car tracks or over any road roughness which tends to throw the car off the course which you intended. Moral: Even a driver who is capable of absolute accuracy of direction cannot hold his course accurately if there are any delays or lags in his nervous and muscular systems.

When you try to maintain an even speed while driving at night, up-grades and down-grades make this difficult because you seldom can see them until they have made the car go slower or faster. In this case, likewise, if you are slow to feel the decelerations and accelerations, or if you do not frequently glance at the speedometer and rely entirely upon your imperfect speed sense, you will not succeed in maintaining uniform speed.

In the first case, it may be assumed that the car responds instantaneously to the wheel. This analogy is applicable, therefore, to automatic control of voltage, illumination, etc.

In the second case we have not merely an analogy but an identity, namely, that of automatic control of speed. The analogy, therefore, is to automatic control problems where there is energy storage, also called the flywheel effect, the inertia effect, the reservoir effect, etc.

Thus there are differences in applications—even though we have been dealing with one application, namely, an automobile—but it nevertheless is obvious that a slow-reacting driver is an inaccurate driver. It is possible to assert that an automatic controller which is slow cannot control closely—provided that this automatic controller may be compared to an automobile driver. Are all automatic controllers thus comparable to automobile drivers? Only in the broadest sense. To generalize would be risky. The thing to do, therefore, is not to generalize but to analyze.

YOU ASKED FOR IT!

This is another fragmentary foretaste of the forthcoming revised edition of "Temperature Measurement and Control." It is, however, a *self-contained article* which does not require reference to other parts of the book. It includes elementary and advancd matter—in compliance with requests from widely-different sources: from users of instruments (who must be served first), from men in charge of training courses and from engineering professors. Although it is mostly my 1929-31 stuff, it includes also extracts from lectures I am giving this year. It will not appear in this repetitious form in the new edition of "T.M.&C." so use whatever portions you need.—MFB

2. Principal Classification of Time Factors

To analyze time factors and their effect, we must first classify them. We must see where each belongs.

One method of classification made itself fairly evident in the car-driving analogy: the time factors belonging to the driver and those belonging to his car. In automatic control, all time factors can be divided into two classes:

(1) The first class includes all time factors inherent in the automatic controller and independent of the process or application.

(2) The second class includes all time effects inherent in *or introduced by* the process or application and essentially independent of the controller itself.

*This was published as a self-contained article: "Some ABC's of Automatic Temperature Control," *Instruments*, Vol. 13, Dec. 1940, pages 397-402.

For convenience, we shall in many cases lump together (or "add" in a way to be explained later) all time factors inherent in the controller, and simply refer to *the controller period*. But we shall only do that after we have begun to classify and discuss the various controller time factors.

In like manner we shall find it convenient (without making our treatment less rigorous) to disregard individual components of some overall time effects belonging to the process, and to deal simply with *the application lag*. But we shall likewise have to recognize that there may be different kinds of time factors in an application.

A second classification of time factors is according to their order—"great," "medium" and "small." These are relative words, which cannot be used to establish mutually-exclusive classes. They can only be used for establishing *grades* of time factors, without sharp boundaries between "slow," "medium" and "fast," unless dividing lines are set up by arbitrary definitions—the result being one man's system, convenient for him but seldom helpful or even convenient for others. In discussing automatic control, it should always be clearly understood that the use of any of these terms implies a different order. That is to say, when a case under discussion involves minutes, then "great" refers to days or weeks and "small" refers to hundredths or thousandths of a second.

A third method of classification of time factors is according to their essential nature: according to the shapes of the curves which would represent them in the familiar plots or graphs. Using this general method, we find that the simplest specific scheme is a twofold division:

(1) Delays; (2) Lags.

(1) A simple delay is the time interval during which the operation being discussed has not yet taken place. Presumably, then, the instant the delay is over, the action will be performed instantaneously. A homely analogy is the reaction-time of a motorist. A military analogy is the pre-set time of a fuze or of a delayed-action mechanism. An electrical-engineering analogy is the pre-set time of a "definite time-delay relay" (perfect name!). Note that in speaking of simple delays in automatic-control technology we are not concerned with the exact nature of their causes. Some of these causes are gradual physical phenomena, in many cases some kinds of energy accumulation or "build-up" which are plotted as exponential functions of time. We are concerned with these simple delays themselves as the causes of control effects. Note also that in automatic control we would not apply the term "delay" to the infinitude of time intervals which is a characteristic of what is called an "inverse-time-delay relay." In automatic control, a time interval which is a function of something other than time is called a *period*.

(2) A lag is a retardation without delay. It is an effect which starts the instant the cause comes into existence. Its graph is a curved line, not a square-cornered line. There are many types of lag. The most familiar is the heating curve or cooling curve of an object suddenly transferred from one constant temperature to another constant temperature. "True thermometric lag" is the behavior of the indicating element of an ideally simple thermometer whose bulb is exposed to a sudden temperature change or to a temperature variation: it follows a fairly simple mathematical law, which will be explained in detail in the next section because it is the most important law to learn in connection with the performance of automatic controllers.

There is a third class of time factor, but we do not call it "Class 3" because in automatic control it sometimes has the effect of a delay and sometimes the effect of a lag. The most familiar example is the travel of the stem of a valve which is driven by a uniform-speed motor. For all practical purposes we may consider that the motor gets up to full speed in an instant and that it stops instantaneously. (The "motor" may be a capsular spring.) Now, if the valve is a pilot valve and if it merely controls the flow of a fluid to a snap switch or, on-and-off main valve, then the time factor is a type of delay. But if the valve is the main valve which controls the flow of energy to the process, then the time factor—the time effect—is a gradual one without delay: it is a type of lag. Moreover, this particular lag can seldom be definitely classified as a component of the controller period or as a component of the application lag. If we consider the constant-speed motor, the operation time factor certainly belongs to the control system; if we consider the energy flow, the changing rate of this flow belongs to the application. In solving a process control problem it does not matter, because we have to put the controller data and the application data into our equations and solve for whatever unknown we are after.

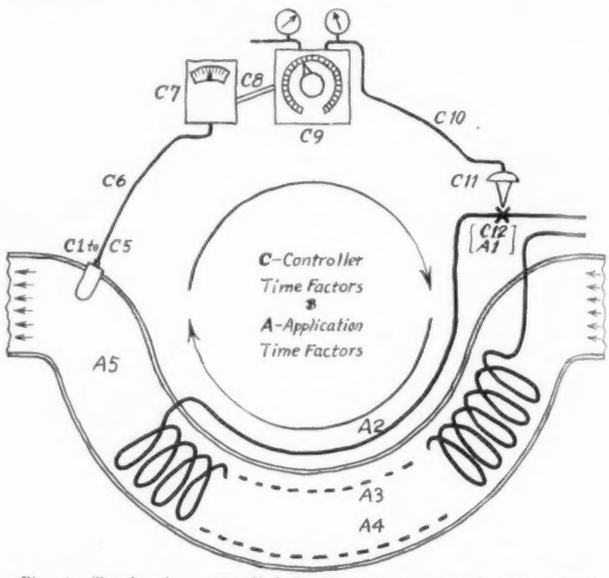


Fig. 1. Sketch of a controlled heating process, showing time factors. In a protected bulb, for example, there are at least two surface lags and two thickness lags. On the other hand, usual construction reduces C7-C8-C9 to one.

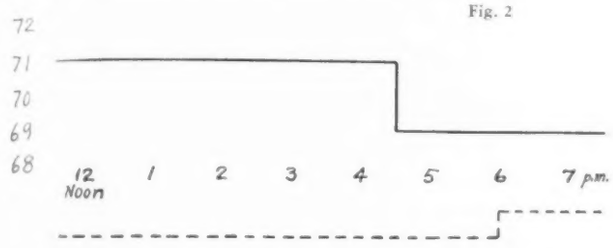
All this will be amplified and treated mathematically in Sections 3 and 4. As a substitute for these Sections, non-mathematical readers can obtain helpful concepts by studying Fig. 1, memorizing it, keeping it in front of the mind for several days and just letting the back of the mind do its stuff.* Read the remainder of this section. Don't try to think hard. Before many days have passed (it usually takes three or four nights of "sleeping over it") the subconscious will have brought to the surface a clear understanding of what happens and why, without any conscious mental effort on your part. Of course your ideas will not be quantitative: you will not be able to write down exact numbers and solve equations, but if you have ever worked where processes are controlled—especially if you have been fortunate enough to be able to observe the recorder charts day after day—your ideas will be right. And in the selection, application and maintenance of automatic control systems it's better to have right ideas without knowing what dy/dx means than to have won honors in mathematics without having acquired the "feel" of the sequence of events in a process-control installation.

In connection with Fig. 1 (and also as a substitute for, or introduction to, Sections 3 and 4) there are given in Figs. 2-5 the graphs of the three types of time factors. For the sake of convenience they are discussed as controller time factors.

*Mathematically-trained readers, of course, will find Fig. 1 and the following a simple *introduction* to Sections 3 and 4. Many such readers, if employed in process-control work and enjoying the authority to make various adjustments and check the results against the equations disclosed later in this chapter, will undoubtedly be able to acquire, by their own efforts, a far more intimate and exact knowledge of the behavior of their controllers than that possessed by any outside consultant (such as me, needless to specify!) But if any graduate physicist or chemical engineer thinks he can forge ahead in process work by coasting along on his mathematical prowess without experimenting, without making a special study of the modern automatic control systems, without going beyond this book and studying the papers by authorities employed by instrument companies, and also the treatments by Grebe, Draper, Zucrow, Spitzglass, Trinks, Keppler, Tenot, LeCorbeller, Hazen and others outside the instrument industry he is due for a rude awakening. Mathematics alone cannot give the sense of timing.

g. 2 is the graph of any delay. The thick line represents the record that would be produced by a quickly-responsive recorder. It shows a sudden departure at 4:30 p.m., specifically a sudden drop from "71" to "69." The thin line represents the behavior of some part of the controller, for example a record of the position of this part. Note that this

Fig. 2



part does not deflect until 6 p.m., when it suddenly moves upward. No scale showing the extent of the deflection is included in Fig. 2, because the only purpose of this diagram is to show the nature of a simple delay. The time scale is unusual in that it is divided in hours. In industry we ordinarily find that delays due to parts of controllers are of the order of seconds or of minutes. Therefore it may be inferred that the delay illustrated in Fig. 2 is a characteristic of a room thermostat.

Fig. 2 might serve also to represent other time effects. For example it might be not merely one particular time factor but the total period or dead-time of a thermostat *for a two-degree drop*, as recorded during a test. The controller period, as was pointed out, is not a single definite delay: it is a time which depends on the extent of the temperature drop or rise, and on other conditions. In that case, therefore, Fig. 2 would represent only one of a series of test results. The next test might be for a 10° sudden drop from 71° to 61° and it would probably show a much shorter dead-time, say a quarter-hour. In a third test, for a 20° sudden drop (from 71° to 51°), this same thermostat would probably show a dead-time of only two minutes or so.

Obviously, then, when we come across a variable delay, we should not only consider it as a cause of controller time effects but we should consider it as an effect in itself. When we look into its cause, we may discover that the cause is a physical phenomenon which has a *curve* for its time graph.

This brings us to *lags*. Fig. 3 shows the most common type. The thick line is a true record of a sudden departure which occurred at 1:01:10 p.m. The middle part is a sketch of a strip of motion picture film of the thermometer, the photographs having been taken at ten-second intervals. The lower part is the continuous-line curve of the thermometer's behavior. It is known by various names, each referring to some of its interesting properties:

"Asymptotic"	"Logarithmic Decrement"
"Newton's Law of Cooling"	"Exponential"

(Many non-mathematical readers will no doubt have seen these terms used in various texts. Every such reader is urged to look up the books which *he* finds relatively easy to study.)

These terms all have similar practical meanings.

The adjective *asymptotic* simply means that the reading of the thermometer approaches the lower temperature more and more slowly. Theoretically, the curve will "never" merge into the straight line representing its limiting value. Practically, the thermometer is said to have stopped going down when its rate of fall is too slow to be detected.

Newton's Law of Cooling simply says that rate of cooling of a cooling body is inversely proportional to the difference between the temperature of the body and the temperature of its surroundings.

Logarithmic decrement means, in this case, what has been explained in the two preceding paragraphs.

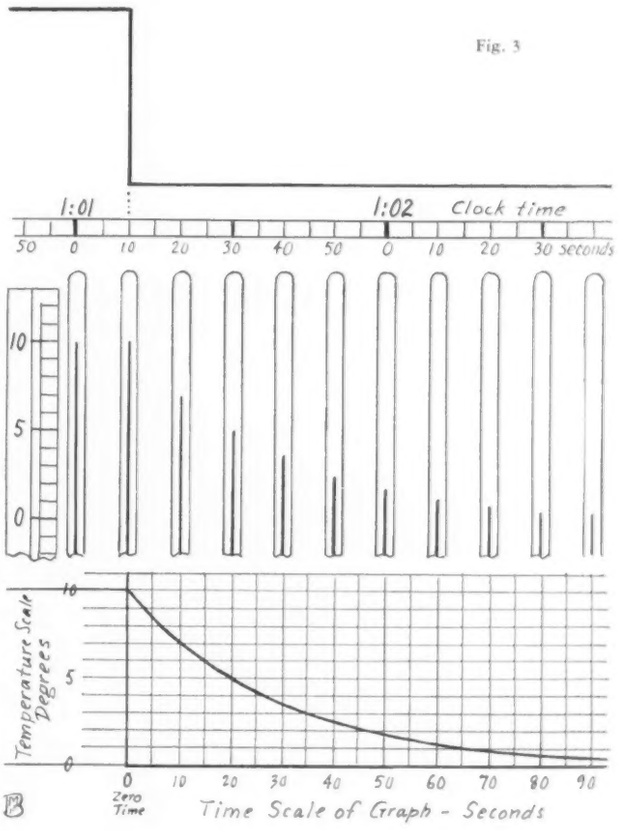
The word *exponential* is derived from "exponent" which is the name of the number of times a number is multiplied by itself. The volume of a cube is the "cube" or third power of its side. This is written $V = S^3$ and the figure three is the exponent. In the equation $S = V^{-3}$ the exponent is minus three and it means the cube root. In the expression A^x the symbol x is the exponent. The equation $P = At$ means that the pressure P varies in exact proportion to the time t. The equation $P = A^t$ means that the pressure P at the time t may be found by raising the constant number A to a power defined by the time t. If A equals one, the pressure remains constant. If $A = 3$, then (assuming that the minute is the time unit) the pressure-time relation will be as follows:

Minutes	1	2	3	4	5	. . .
Pressure	3	9	27	81	243	. . .

But if the constant A is a fraction between zero and one, the pressure will go down as time passes. It will go down asymptotically with zero pressure as the limiting value.

Note that if the constant A is a number greater than one, the equation $P = A^{-t}$, in which the exponent is minus t, will likewise represent a gradual pressure drop, approaching zero pressure as its asymptote. For example, if the constant value of A is 1000, then with a minus exponent we get the following:

Fig. 3



Time	1	2	3	4	5
Pressures	1000	31.6	10.0	5.61	2.15

These rough examples would horrify a math prof but they serve to lead up to the number called e. In the above pressure-time equations we used A for a constant and we tried out various values of A. But in practical lag equations it is found convenient to use the constant called e, whose value is "natural" (just as the "natural" value of π is 3.14159.....). The numerical value of e is 2.71828..... and it is not only the base of natural logarithms but is more widely useful than π. By using it, we save as much time as the schoolboy does when he computes the area of a circle with the aid of π. Without it, we would be stuck almost as badly as a schoolboy who has forgotten πr^2. So don't glance away when you see an expression like e^{-kt}.

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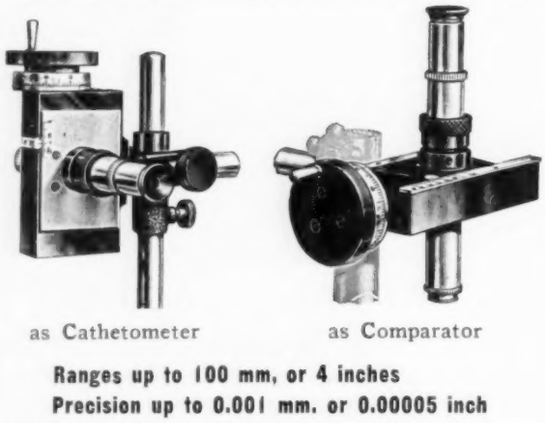

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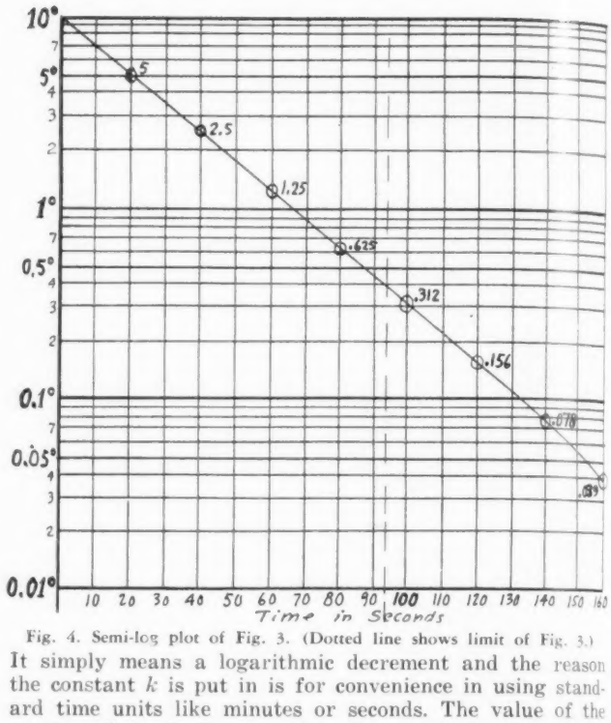


Fig. 4. Semi-log plot of Fig. 3. (Dotted line shows limit of Fig. 3.)

It simply means a logarithmic decrement and the reason the constant k is put in is for convenience in using standard time units like minutes or seconds. The value of the constant k in the lag equation of a particular instrument or process is taken from the graph obtained in a test; sometimes it is supplied by the manufacturer so that the user is not only saved the trouble of running a test but can predict what the time effects will be when the device whose k is known for one set of conditions is used under a different set.

Kinship of "Lag" and "Log"—Fig. 4 shows the same lag characteristic as that shown in the lower portion of Fig. 3. It looks different but the numerical values are the same. The time scale is linear as before but the temperature scale is logarithmic. The curve has been plotted on "semi-logarithmic coördinates"—"semi-log paper" for short. Most logarithmic or exponential relations, especially those involved in process control, plot as straight lines on semi-log paper. The thermometric lag does so by definition. You can buy, in any large stationery store, sheets of semi-log cross-ruled paper with any convenient number of decimal "orders" or "cycles." You don't have to learn calculus to use semi-log paper intelligently; and when you start using it you will be on your way to becoming a Sherlock Holmes with regard to control problems. One reason is that the lags in a well-behaved controller or process plot as straight lines. Thus the meaning of the slope k which was difficult to conceive as a "constant" when looking at Fig. 3, becomes obvious on a semi-log plot: it is the actual slope at any point. When it varies on the semi-log plot of an actual lag test, we can pick up clues to the physical causes of the bad behavior, by noting how much and where—or, rather, "when"—the value of k changes. (Most frequent cause in thermal systems: heat conduction between equipment wall and primary element.)

Fig. 5 is a graph of the hybrid type of time factor which is a delay in some cases and a lag in others. It represents

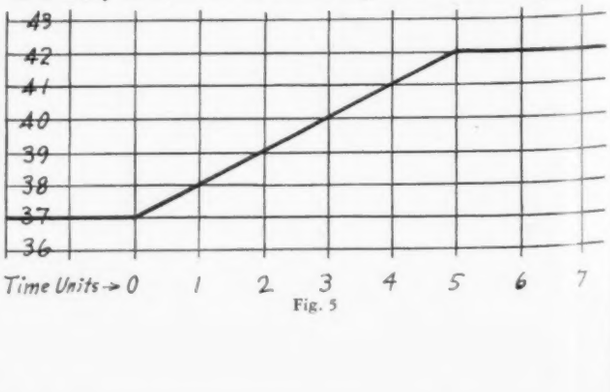


Fig. 5

uniform motion, or uniform change of rate of flow, or uniform increase or decrease in general. In control systems we meet it in connection with various parts, either in the power unit (example, a constant-speed motor) or in a part designed as a "stabilizer" or "droop-correction" or "anti-hunting" (examples, a leak orifice, a leak resistor, a spring-and-dashpot, etc., all having linear characteristics). In processes, there are innumerable examples.

3. Analytical Treatment of Controller Period

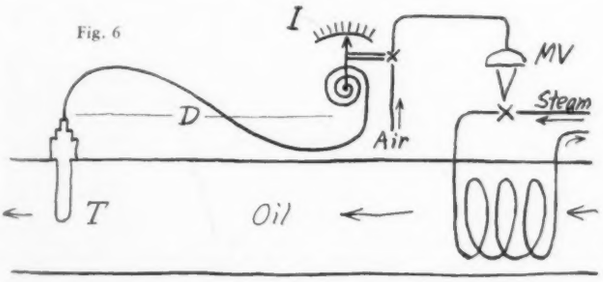
If optimum control is desired, the controller period for any given departure from normality should be *determinable* and it should always be the same for such a given departure (under similar conditions of adjustment, etc.).

The controller period is neither a definite delay nor a lag. It is the total effect of controller time factors (delays and lags) plus the effect of controller characteristics *not* related to time—particularly the overall sensitiveness.

Note that we say "the total effect" but not "the sum": in a relatively complex system where some physical elements are in parallel rather than in series, a time factor associated with a physical part in one branch may be entirely masked by a time factor of longer resultant period associated with a part in another branch. For analytical purposes, however, we shall deal with series systems in which the succession of time factors and of physical effects (such as deflections, etc.) follow the same path in the same direction, namely from the primary element to the "controlled valve." (This is the generic term for the final element which is commanded by the instrument but which itself controls or governs a flow of energy. It might be a rheostat.)

An automatic control system usually constitutes one of the two halves of a closed dynamic system, the other half being the application. In the application, the time factors and the consequent chain of events follow a path in one direction, namely from the controlled valve to the primary

Fig. 6



element. Thus the entire system of controller and application is not only a closed dynamic system but a closed circuit. This concept is not only helpful but necessary in solving problems of *stability*—in designing anti-hunting features.

This concept of two coupled systems is neither necessary nor even helpful in determining controller periods. By definition, all controller periods are intrinsic characteristics of elements of the controller. They are variable in the limited sense of being functions of departures from normality, of adjustments in the controller itself, and of other given or determinable data.

Temperature control furnishes simple and helpful examples of component periods as functions of departure from normality. Such examples will be discussed first; and they will be followed by others covering the control of pressure and other variables.

Consider a temperature controller (Fig. 6) the primary element of which is a mercury-filled bulb located at distance D from indicator I. This indicator serves also to regulate the supply of compressed air to diaphragm-motor valve MV. This d-m-v. controls the flow-rate of B.t.u's (steam) through the coils which heat the oil. The flow-rate of the oil, or its initial temperature, or both, are variable.

Assume an initial steady state, with the thermal system in equilibrium: $I = T$ (or, in plain words, the pointer reading is correct).

Assume that the thermal system terminating at I is ideally sensitive. It responds to small departures—even to

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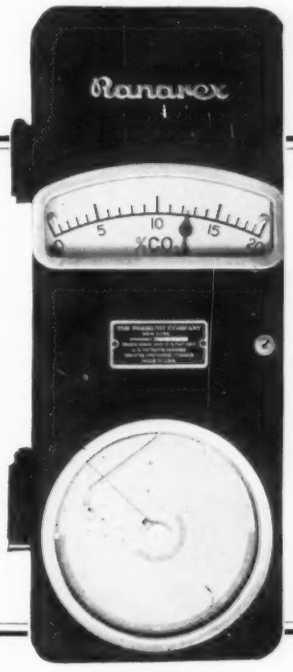

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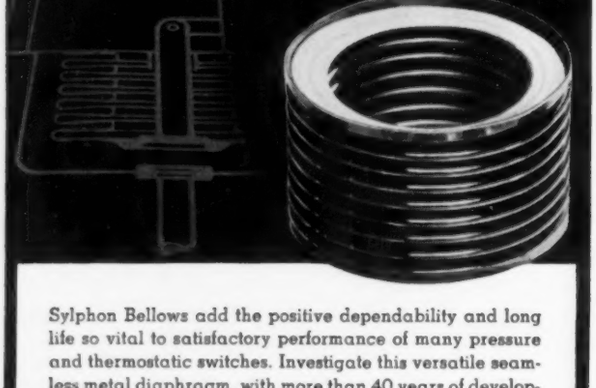

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infinitesimally small departures. However, its initial rate of response varies. For a small sudden change in T, we observe (qualitatively) that the initial rate of pointer displacement is small; and that for a medium sudden change in T, this initial rate is medium. We are led to infer that in each case the pointer takes the same time to reach its final position—which final position determines a changed flow of air to *MV* and hence a changed steam valve opening and a changed rate of B.t.u's to the oil.

How nearly correct is this inference? In Figs. 7 and 8, the oil temperatures T, the pointer readings I and the times t are plotted on linear coördinates. A glance shows that the shapes of the curves of the pointer displacement will provide the answer. Closer examination leads us to infer that both curves seem to obey the same law. This second inference is correct. If we take the curve for the 1° change and superimpose it on the upper end of the curve for the 10° change, we find that the curves fit exactly over the same 9° span. Hence, once we find the shape of the curve we shall find the time factors involved for any change in temperature, for *this* system. If we were to take another type of thermal system, we would get curves of slightly different shapes, but still showing the same characteristics; i.e., faster rates of change for greater changes, and all curves for all changes falling on the same general curve.

We are justified in concluding that for any *one* system we should be able to find a mathematical expression for the shape of the curve. And also, that this expression should contain a factor that will fit the curve to different systems.

The mathematical expression for a curve that approaches a line at a rate proportional to the distance from that line is of the form

$$T = T_F - (T_F - T_0)\ e^{-kt} \quad . \quad . \quad . \quad . \quad (1)$$

where T is the temperature at time t;
t is the time;
T_0 is the initial temperature: and
T_F is the final temperature.

It is convenient to represent $T - T_F$ by Δ; and $T_0 - T_F$ by T_D.

Then, $$\Delta = T_D e^{-kt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In (1) and (2), e is the base of natural logarithms, numerical value 2.71828 . . . .

PROOF

$$\frac{dT}{dt} = k\ (T_F - T)$$

$$\therefore \int_{T_0}^{T} \frac{dT}{T_F - T} = k \int_0^t dt$$

$$-\log\ (T_F - T) \Big]_{T_0}^{T} = kt \Big]_0^t$$

or, $$\log \frac{T_F - T_0}{T_F - T} = kt$$

or, $$\log \frac{T_F - T}{T_F - T_0} = -kt$$

$$\therefore \quad T_F - T = (T_F - T_0)\ e^{-kt}$$

$$\therefore \quad T = T_F - (T_F - T_0)\ e^{-kt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let $-T_F + T_0 = T_D$ and $T - T_F = \Delta$,

$$\Delta = T_D\ e^{-kt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Equations (1) and (2) are two convenient forms of the equation for *Thermometric Lag*, which represents the behavior of *any* measuring-system pointer whose initial rate of displacement is proportional to the amount of departure from normality; whose rate of pointer displacement dI/dt at any time is proportional to the remaining difference Δ_2 (to use a notation we shall find useful later).

Theoretically, $I_F = T_F$ at $t = \infty$. In any actual controller, however, this purely mathematical property of the lag equation has no practical physical effect. In the first place, the physical dimensions are such that 99% (or even less) of the pointer travel has practically the same effect on the con-

trolled valve as 100% would have. In the second place, the departures in a continuous process (and the departure after starting up a batch process by manual control) are relatively small, so that even the extremely small friction in a high grade controller conceals or masks the difference between 95% and 100% of the correspondingly small total displacement.

And in the third place, when a large departure does occur by reason of a process disturbance, the controller will usually have initiated a correction before the pointer has traveled more than 5% or so; and the temperature or other controlled variable will usually be returning to normality—unless application lags are excessive—*before* the pointer has reached 50% or even 20% of what its total travel *would* have been.

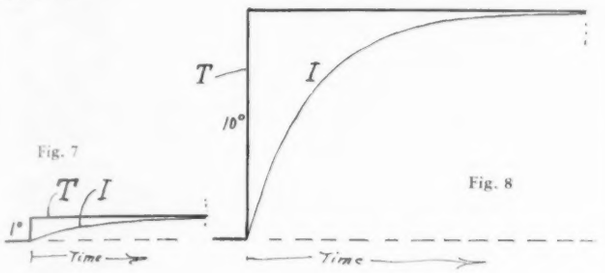


Fig. 7

Fig. 8

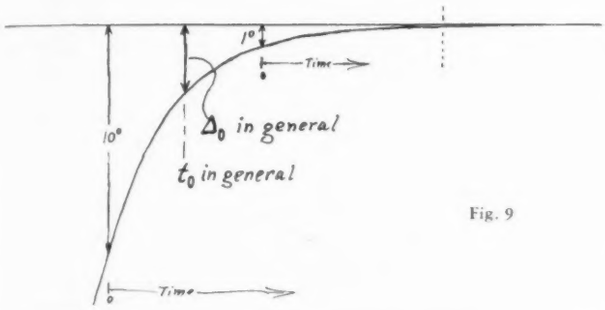


Fig. 9

This would not be true, however, if the thermal system of the controller were so "fast" that the pointer completes 99% of its travel in a matter of seconds where application lags are of the order of hours. So far, we have not dealt with this question. Let us consider lag coefficients.

"Fast" and "Slow" Systems.—In the example illustrated in Fig. 6, we considered a mercury-filled thermal system, presumably with its steel bulb in direct contact with the oil being processed. How would the equations be affected if we substituted a gas-filled system, or if we placed the mercury-system bulb in a low-conductivity protecting socket? The rates of response would be lower but the law of thermometric lag would still hold. Fig. 10 shows the comparison. The equation

$$\Delta = T_D\, e^{-kt}$$

can be made to fit both these curves by changing the constant k. This constant of attenuation, as it sometimes is called, provides one way of quantitatively comparing various responses. Another way, more frequently used because of the unique properties of e, is to use the *coefficient of thermometric lag* (symbol, L).

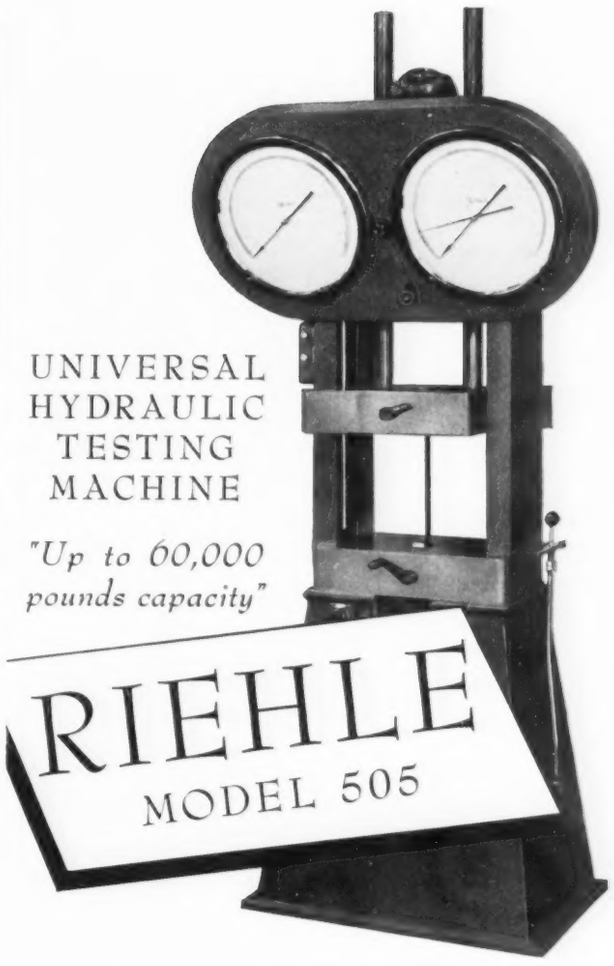
This coefficient L is not a dimensionless number like the Reynolds Number, but a characteristic time—the time for the temperature difference to become $1/e$ or $1/2.718$ of its original value. Furthermore, it is the reciprocal of the constant of attenuation k. For, if

$$\Delta_1 = T_D\, e^{-kt_1} \quad \text{and} \quad \Delta_2 = T_D\, e^{-kt_2}$$

and $$\frac{\Delta_2}{\Delta_1} = \frac{1}{e} = e^{-1} = e^{-k(t_2 - t_1)}$$

Then $$t_2 - t_1 = \frac{1}{k}$$

A property of measuring-system indicating elements whose displacement obeys the thermometric lag law is that the time required for the change in indication to reach any



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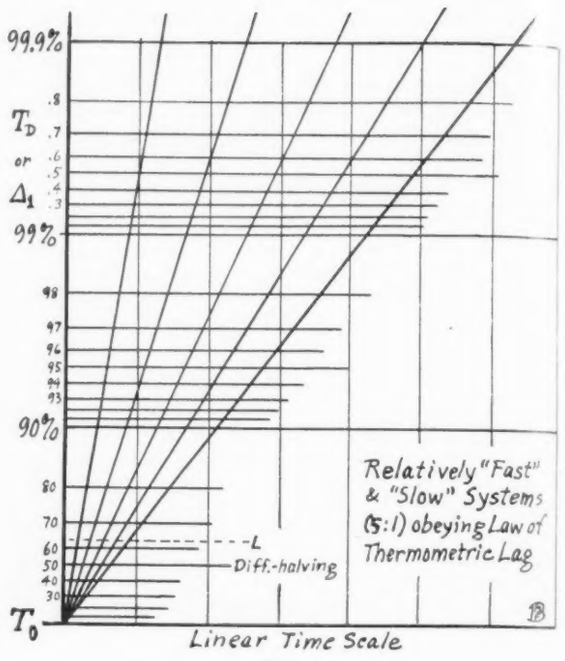

Fig. 10

given fraction of the final value is a constant. Also, the *difference-halving period* is, roughly, ⅔ of the lag coefficient L. For if

$$\frac{\Delta_2}{\Delta_1} = \frac{1}{2} = e^{-k(t_2 - t_1)}$$

$$\log_e \frac{1}{2} = -k\,(t_2 - t_1)$$

or, $$-\log_e \frac{2}{1} = -k\,(t_2 - t_1)$$

$$\therefore \quad t_2 - t_1 = \frac{1}{k} \log_e 2$$

But $1/k \equiv L$. $\quad \therefore\ t_2 - t_1 = L \log 2 \approx \frac{2}{3} L$

The Delayed Start and the Delayed End. — Although practically negligible in most measuring systems of automatic controllers, divergences from the law of thermometric lag characterize all composite structures. No man-made thermometer obeys the law exactly. For a full discussion see the Section on Thermometric lag in Chapter III. Even a brief mathematical treatment may be omitted here. Suffice it to mention that Newton postulated an ideally simple "body" in formulating his Law of Cooling from which the lag equations were derived by Harper; that there is no such body in the measuring systems of controllers; that consequently there is no "average" temperature to make I a precisely determinable and predictable function of t; and that the most noticeable effects of structural complexity occur in the first 10% or so and in the last 10% or so of the pointer deflection (See Fig. 11). We may call these effects the delayed start and the delayed end (or *premature stop* when serious).

The delayed start is especially noticeable where a heavily-protected thermocouple is connected to a direct-defletcion millivoltmeter.* As a rule it is due to relatively low thermal conductivity. The delayed end is especially noticeable where the ratio of the bulb volume to the capillary volume is uncommonly low and where more than 10% or so of the capillary is in effect a secondary bulb. In measurement, the delayed start is ordinarily unimportant and the delayed

*It is noticeable also—paradoxically—where mercury (or xylene, etc.) is enclosed in a *thin*-walled bulb. Such a bulb attains its final expansion (or contraction) before the average temperature of the enclosed liquid has had time to rise (or fall) appreciably. That this fact is not unknown to the general public is indicated by a question asked in a radio quiz program in 1940: "Why does a thermometer *fall* when you suddenly place it in boiling water?"

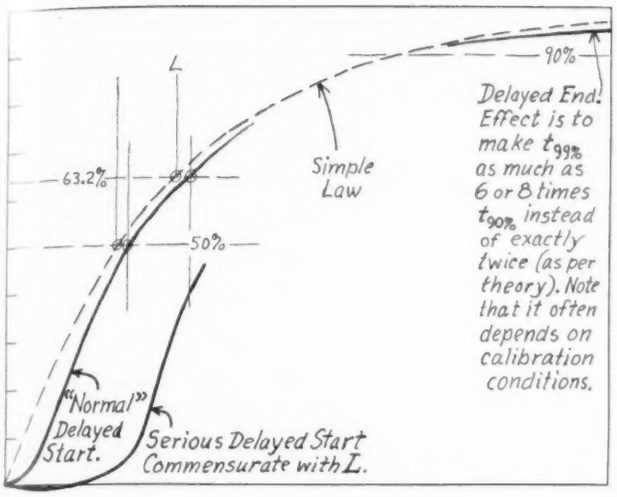
L
90%
63.2%
50%
Simple Law
Delayed End. Effect is to make $t_{99\%}$ as much as 6 or 8 times $t_{90\%}$ instead of exactly twice (as per theory). Note that it often depends on calibration conditions.
"Normal" Delayed Start.
Serious Delayed Start Commensurate with L.

Fig. 11

end is frequently a source of error. In control, even a premature stop is of no practical consequence but the delayed start is the effect to be borne in mind.

According to the simple law of thermometric lag, the rate of pointer deflection is inversely proportional to t. Therefore, if we know the difference-halving period, or any other one pair of deflection and time data, we can obtain k and we can plot the entire curve by drawing a straight line on semi-log coördinates. Delayed-start effects or delayed-end effects impair the strict exactitude of the relations. A glance at Fig. 11 shows, however, that the ⅔ relation of L to the difference-halving period is affected but little by the delayed start and affected not at all by the delayed end. The chief sufferer is the constant k. Practical workers, when running tests of thermal systems, may use the ⅔ relation unquestioningly. Only research workers, or process engineers striving for hairline control, need bother about the value of k being different at the start. Moreover, we shall see in what follows that the overall sensitiveness of the controller and the mode of control (on-and-off, throttling, etc.) must be considered before going to the trouble of determining the exact times involved in delayed-start effects.

On the whole we see no reason for making the remainder of this discussion difficult to follow by complicating the equations. We shall go on using the simple Newton's Law.

How Sensitiveness Affects Periods and *Vice Versa*

No controller is entirely free from time factors. All are characterized by at least one lag—even if negligible in comparison with the applicaton lags.

No controller has an ideally sensitive measuring system. All are characterized by a definite—even if negligible—sensitiveness.

Up to now in this discussion we have considered lag, but in our examples the function of the pointer was to actuate a pilot valve continuously. It was implied (nothing being said to the contrary) that the combination of pointer and pilot valve was free from backlash or other imperfections. It was implied, therefore, that even an infinitesimal change in the indication will cause a change in the opening of the controlled valve.

Before dropping these assumption, it is in order to point out first of all that the delayed-start effect creates a sensitiveness zone of appreciable width, even in a controller which otherwise would be ideally sensitive. For example, assume that the thermal system has a difference-halving period of 20 seconds and consequently that $L = 30$ seconds but that the constancy of k is sharply modified at the beginning of the curve, there being a "plain delay" of 1 second before the pointer even starts to move. Obviously, no change in the temperature under control will result in any pointer deflection for a period of one second and there will be no controlled-valve movement at all during that period, however great or small the departure from the setting "point." In the event of a sudden departure, therefore, such a con-

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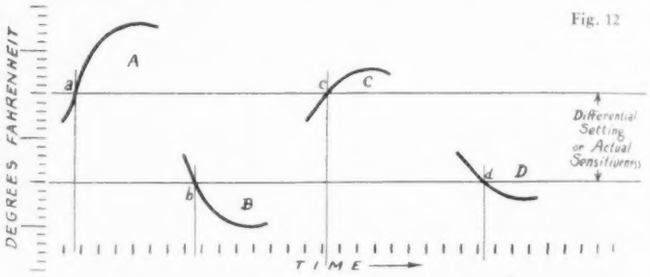
troller would have *an infinitely wide dead-zone*. In the event that T changes at a uniform rate, the dead zone will be, in degrees, the degrees-per-second rate of change of T. In any actual installation, excessive thermal insulation of the primary element impairs the sensitiveness of a temperature controller and, in general, whatever impairs the immediacy of the pointer response or of the overall response in any control application (pressure, pH, etc.) makes close control impossible. The writer preaches it as a slogan: Dead Times Mean Dead Zones.

Equally true is the converse: dead zones mean dead times. But the onerous term "dead zone," implying an undesired and objectionable characteristic, will not be used in referring specifically to a distance between contacts, or to another deliberately-introduced and known sensitiveness, and in discussing the determinable periods resulting therefrom.

Example I

For a first example we may consider an electric-contact type temperature controller with a sensitiveness of say 10°F. (determined by a differential setting of that amount) and with *no time factors* such as delays or lags in the measuring system which terminates in the contact-making pointer. A quantitative analysis need not be undertaken to determine the time characteristics of this controller: Obviously it will not initiate any change in the heat supply to the process while T remains within the zone of normality.

Fig. 12



Therefore its period is indefinite. But not infinite: In the event of any departure from normality, this controller will not fail to act. Its behavior is illustrated in Fig. 12. An 8° departure is shown at A, a 5° departure at B, a 3° departure at C and a 2° departure at D. The curves are graphs of both T and I since, there being no lag, $I = T$ at all times.* Points a, b, c and d are the *instants* when the controller acts—when it acts instantaneously.

We pass on, now, from hypothetical to actual controllers —controllers characterized by determinable sensitiveness and determinable lag. These two properties, as well as departures and periods, will be discussed as functions of one another.

Example II

Data: Temperature controller (no particular type). Lag coefficient: 30 seconds. Sensitiveness: 1°F. Initial state: $I = T_0$ (that is to say, the process has not yet been upset and the pointer indication corresponds exactly to the controlled temperature).

Required: The period in the event of a 10° sudden departure.

There is some ambiguity in the "sensitiveness" datum, in that it implies ±0.5°, but we may proceed on the assumption that the pointer may deflect over one full degree (i.e., from $I = T_0$ to $I = T_0 + 1°$) before the controller initiates a corrective action.

Mathematical Solution: In the discussion of the thermometric lag equation it was shown that the difference-halving period is 2/3 of L, specifically $L \times \log_e 2$, because of

*This is an imaginary measuring system. Any actual kinetic system, where forces move masses, is characterized by inertial lag, friction, etc., however great the ratio (torque)/(friction + moment of inertia). However, we are not specifying any time units in this example, so that the lag of an actual system may be truly negligible. Thus, in Fig. 12, if the time divisions are hours, the points a, b, c, and d are (relatively) instants.

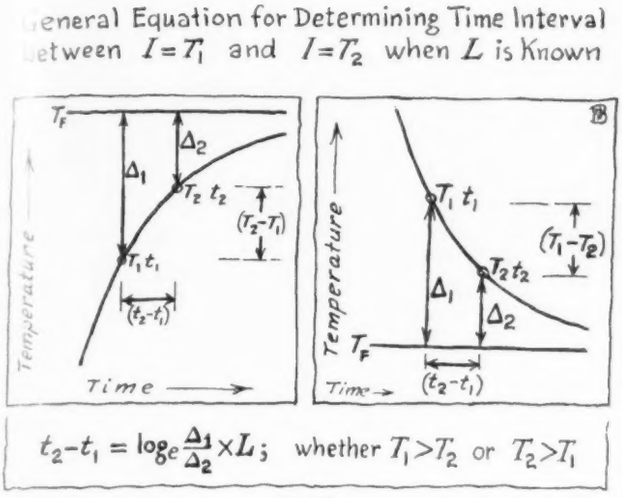


Fig. 13

the general property of this form of equation. In this case the required period is that for one-tenth of $T_F - T_0$.

$$\text{Therefore the period} = L \log_e \frac{10}{10-1}$$

$$= 30 \times 0.10 = 3.0 \text{ seconds.}$$

Graphic Solution: Measure the t intersection of I and $T_0 + 1°$ (i.e., $T_F - 9°$) on a semi-log plot of I, as shown in Fig. 14.

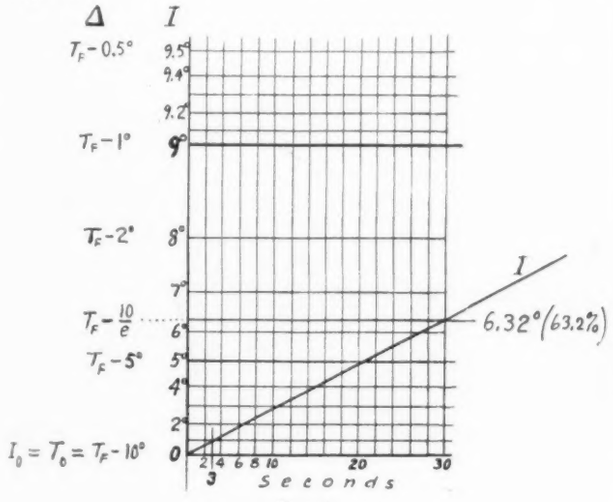


Fig. 14

Example III

Data: Same as in Example II.

Required: The time characteristic or variable period. Plot the period as a function of the departure, from zero departure to 15° departure.

The thermometric lag equation makes it possible to plot the response of the pointer for *all* sudden departures. It has been shown also (see the discussion in connection with Figs. 7 and 8) that the I *vs.* t curve for any departure coincides in part with the curve for any other departure. Thus, in Fig. 15, the portion of the general I-t curve to the right of A represents the pointer response for a 10° de-

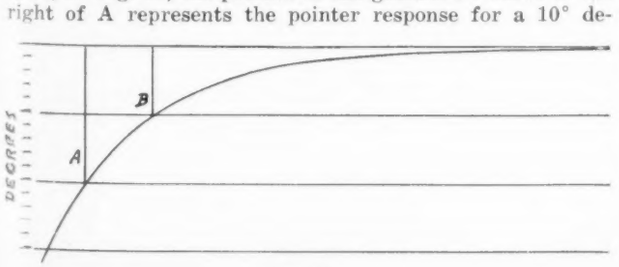
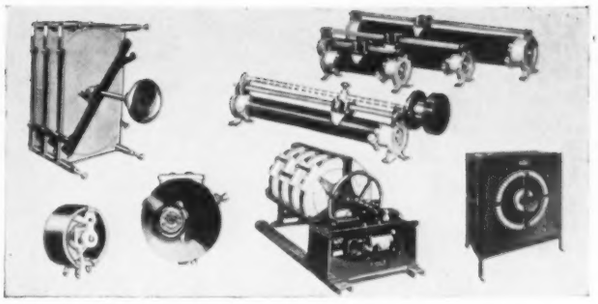


Fig. 15



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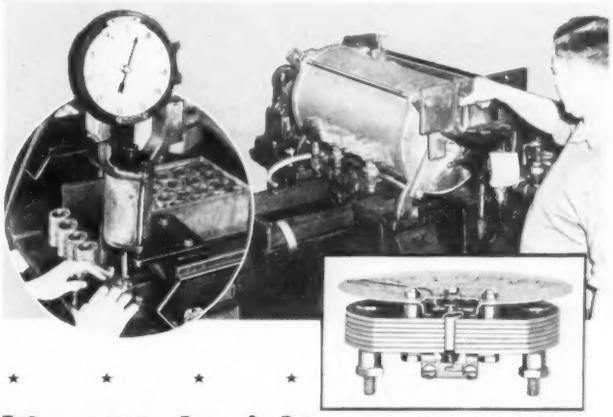

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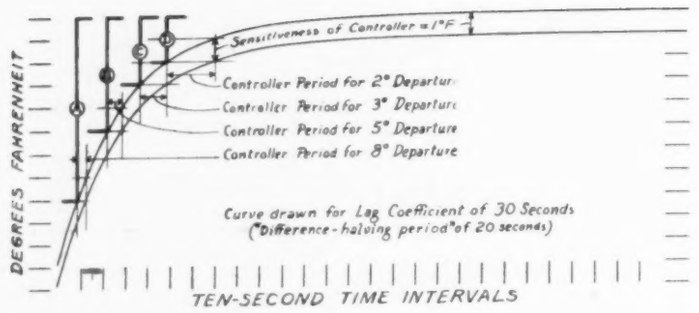
Fig. 16


Sensitiveness of Controller = 1°F
Controller Period for 2° Departure
Controller Period for 3° Departure
Controller Period for 5° Departure
Controller Period for 8° Departure
Curve drawn for Lag Coefficient of 30 Seconds
("Difference-halving period" of 20 seconds)
DEGREES FAHRENHEIT
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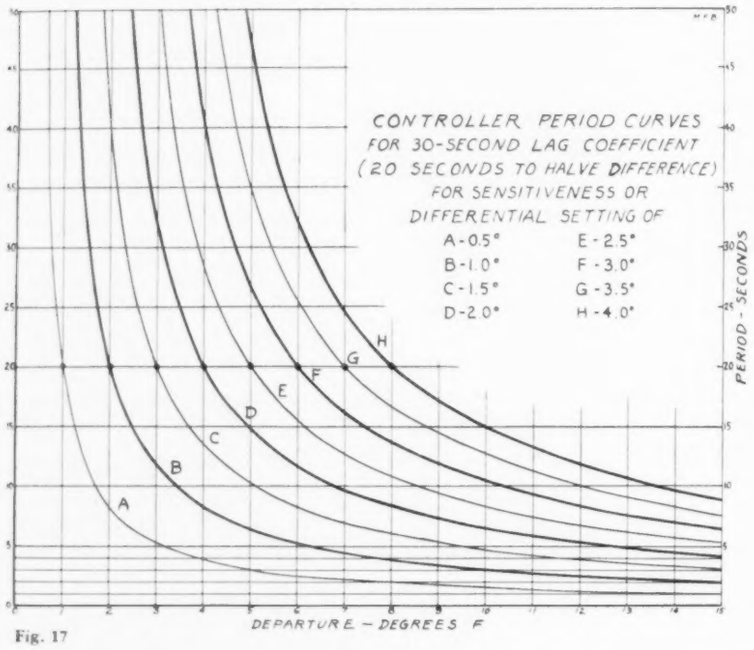
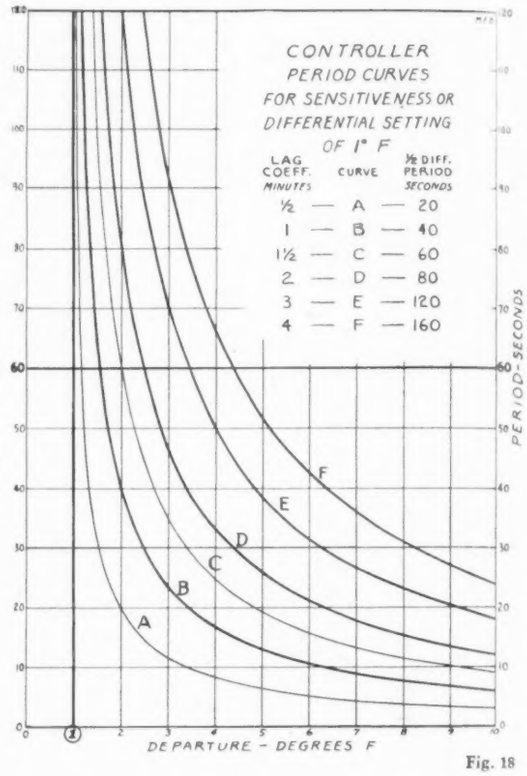


Fig. 17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1½ — C — 60
2 — D — 80
3 — E — 120
4 — F — 160
PERIOD - SECONDS
DEPARTURE - DEGREES F

Fig. 18

parture; likewise, the portion to the right of B describes the pointer behavior for a 5° departure, and so on.

The time-saving graphic-presentation kink illustrated in Fig. 13 suggests the possibility of another legitimate trick. Practical industrial control problems of the type given here do not require fourth-decimal accuracy. Therefore the author devised in 1930 the scheme illustrated in Fig. 16. Some engineers and educators have found it useful; none has found any objection, so it is given as the recommended graphic solution.

Graphic Solution. First Step: Determination.—Since for any departure, the period is the point when the I curve (for that departure) intersects $T_0 \pm 1°$, these points of intersection on an infinite series of I curves will constitute a duplicate of the general curve. By drawing two curves 1° apart on linear coördinate paper, it becomes a simple matter (see Fig. 16) to measure along the time axis the period required for the pointer to travel one degree from any starting point. An 8° departure is shown at A and the corresponding period is 3.75 seconds. The period for the 2° departure D is of course the difference-halving period of 20 seconds. (Note—Its calculated value is 20.97 seconds.) Needless to say, the heavy-line departures and other notations on Fig. 16 need not be drawn and lettered in an actual solution. Only the two curves need be drawn on the cross-section paper.

Second Step: Plotting the Characteristic of the Controller.—By using a pair of dividers it is easy to transfer to another sheet a series of values of the period taken from the first sheet, and then draw a curve through the points thus obtained. In this diagram, temperatures should preferably be the abscissa and times the ordinates, because departures are the knowns and periods the unknowns. The result is curve B (alone) in Fig. 17. As always in plotting a curve from another, the use of proportional dividers enables the worker to choose any convenient actual size.

Discussion.—The controller characteristic thus obtained will plot as a straight line on semi-log paper, for it is a logarithmic relation. Since it is such a curve, it likewise is one of the family of curves obtained by using different values of one of the "coefficients," in the mathematical sense. Therefore, although the controller under consideration has a fixed coefficient of lag and a fixed sensitiveness, it is already evident from this Example that two families of curves will be obtained if either datum is made the only variable. The physical meaning is that we can predict the effects of various adjustments in actual controllers; and this will be taken up in the next two examples.

Example IV

Data: Same controller, but its sensitiveness is adjustable.

Required: The general characteristic: all the periods for all values of departure and all values of sensitiveness (between reasonable limits).

Solution.—The "reasonable limits" are those which apply in any practical industrial problem. Repeat the procedure of Example III, using short-cuts which will now suggest themselves. Semi-log paper may be found a convenience. Fig. 17 shows a solution in which the extreme value of the sudden departure is 15° F. and the longest period 50 seconds.

Discussion.—Some workers may prefer to make the sensitiveness settings the abscissa, the periods the ordinates, and each curve that for one value of a sudden departure.

Example V

Data: Same as in Example III except that L is "adjustable" (see discussion).

Required: The general characteristic: all periods for varying values of departures and lag coefficients.

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I-157 **Mechanical Flowmeters.** Bulletin No. 410, 8½″ × 11″, 4 pages, describes and illustrates flowmeters for all commercial fluids—steam, water, oil, gas, air—shows panel mountings and principal dimensions; also bulletin on orifice meter calibrations. Ring Balance Instrument Co., 740 N. Franklin St., Chicago, Ill.

I-158 **Du Mont "Oscillographer."** Feb.-Mar. 1941, 4 pages, is entirely devoted to article by Alexander Sandow, Dept. of Biology, New York University entitled "A Single-Sweep Stopwatch and Its Use in a Biological Problem." Allen B. Du Mont Labs., Inc., 2 Main Ave., Passaic, N. J.

I-159 **Condensers, Resistors and Test Instruments.** 1941 Catalog, 8½″ × 11″, 20 pages, covers general line of electrolytic, paper, oil, exact-duplicate replacements, transmitting and other condensers, wire-wound and carbon resistors, and L-C checker, capacity-resistance bridge and motor-starting capacitor selector. Aerovox Corp., New Bedford, Mass.

I-160 **Precision Snap Action Switches.** Catalog, 9½″ × 12″, 36 pages, gives dimensions, prices, operating characteristics and applications of the two basic types of switches — externally operated and self-operated. Micro Switch Corp., Freeport, Ill.

I-161 **Electric Furnace.** Bulletin GEA-3523, 8″ × 10½″, 4 pages, describes and illustrates gas-carburizing electric furnace with complete equipment including furnace, loading baskets, cooling unit and standard control panel. General Electric Co., Schenectady, N. Y.

I-162 **Pile Height Micrometer.** Folder, 5½″ × 7″, 4 pages, describes and illustrates micrometer for measurements of the thickness of plush, carpets or similar fabrics to the thousandth of an inch, weight of instrument is 3½ lbs., ½″ capacity. F. F. Metzger & Son, 2600 North 6th St., Philadelphia, Pa.

I-163 **Connectors.** Bulletin P, 8¼″ × 10½″, 18 pages, describes, illustrates and prices line of Type "P" and "O" plugs for sound and allied applications—electronic low level circuits, small power applications, etc. Cannon Electric Development Co., 420 West Avenue 33, Los Angeles, Calif.

I-164 **Boiler Water Feeder and Feeder-Cut-Off Combination.** Form L-28, 8½″ × 11″, 2 pages, describes and illustrates No. 47 feeder and No. 47-2 feeder-cut-off combination for boilers up to 5,000 sq. ft. capacity. McDonnell & Miller, Wrigley Bldg., Chicago, Ill.

I-165 **Electrical Instruments.** Folder E(4) 155-141, 7¾″ × 10½″, 4 pages, covers galvanometers and electro-chemograph, Micromax recorder used in studying plant-cell potentials at Stanford University and lists other instruments in maker's line for research, teaching and testing. Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia, Pa.

I-166 **Projection Reading Analytical Balance.** Bulletin No. 680, 3¾″ × 8⅝″, 4 pages, describes and illustrates analytical balance No. 911 for automatic weighings from 1/10 mg. to 100 mg. ±. Illuminated and graduated micro scale is magnified, projected and read on a matt glass screen. Christian Becker, Inc., 92 Reade St., New York City.

I-167 **All-Electric Floatless Controls.** Catalog 241, 8½″ × 11″, 24 pages, describes and illustrates liquid level control for use on a-c. only, shows special controls and panels, relay switches, a-c. automatic starter and relay combination, etc. Bender-Warrick Corp., Birmingham, Mich.

I-168 **Sight Glasses.** Publication 2970, 8⅜″ × 11″, 2 pages, describes and illustrates sight glasses for visual inspection of flow of liquids and sludge through pipe lines. Cochrane Corp., 17th St. & Allegheny Ave., Philadelphia, Pa.

I-169 **Capacitor Manual.** 1941 Edition, No. 2, 5″ × 7⅜″, 256 pages, catalogues dry electrolytic, wet electrolytic, tubular paper, uncased paper, paper replacement, auto generator and vibrator and mica capacitors for radio servicing; also capacitor analyzer, capacitor bridge and interference filters. Cornell-Dubilier Electric Corp., New Bedford, Mass.

I-170 **Mechanical Tools.** Catalog 26, 5″ × 7″, 282 pages, covers precision tools, steel tapes, dial indicators, hack saws, transits and leveling instruments, calipers and dividers and gages. The L. S. Starrett Co., Athol, Mass.

I-171 **Water Level Control.** Bulletin, 9″ × 11½″, 2 pages, describes low water B-P-10 control, immersion aquastat, surface aquastat and pressure control. Globe Controls Co., 126-128 First St., Newark, N. J.

I-172 **Spot Welding Timers.** Descriptive Data 18-335, 8⅜″ × 11″, 4 pages, describes and illustrates floor-mounted ignitron spot welding timers to control welding of aluminum, heat treated alloys and other materials. Operating details list the functions of tubes and relays and explain how stepless welding is accomplished. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

I-173 **Industrial Power Units and Motorized Valves.** Catalog 77-1, 7¾″ × 10½″, 24 pages, describes line of power units and valves to operate with maker's control instruments, photographs shown of electric control motors, slip stem globe type, rotary stem globe type, butterfly type, pilot operated, three-way and special valves. Brown Instrument Co., Wayne & Roberts Aves., Philadelphia, Pa.

I-174 **Boiler Water Level Control.** Bulletin 431, 8½″ × 11″, 8 pages, describes operating experience at new brewery's boiler plant with Copes flowmatic regulator. Northern Equipment Co., Erie, Pa.

I-175 **Director-Coupled Amplifiers.** Circular, 6″ × 9″, 8 pages, describes and illustrates self-balancing push-pull direct-coupled amplifiers for a wide variety of special laboratory applications. Amplifier Co. of America, 17-19 West 20th St., New York City.

I-176 **Du Mont "Oscillographer."** Vol. 4, Nos. 10 & 11, 6″ × 9″, 4 pages, is entirely devoted to article entitled "A Single-Sweep Stopwatch and Its Use in a Biological Problem." Allen B. Du Mont Laboratories, Inc., 2 Main Ave., Passaic, N. J.

I-177 **Relay Testing Apparatus.** Catalog No. 5, Sec. 1C, 8½″ × 11″, describes and illustrates line of relay testing equipment, including relay loads, test switches and cycle counters. The States Co., Hartford, Conn.

I-178 **Gaseous Discharge Rectifier and Control Rectifier Tubes.** Catalogue, 8¾″ × 11¼″, 26 pages, covers design of rectifier circuits, notes on grid-control rectifiers and data on EL rectifier tubes. Electrons, Inc., 127 Sussex Ave., Newark, N. J.

I-179 **General Radio "Experimenter."** April issue, 8 pages, discusses new terminals for use with coaxial transmission lines and new audio-frequency microvolter. General Radio Co., 30 State St., Cambridge, Mass.

I-180 **Stroboscope Inspection Equipment.** Bulletin GEA-3583, 8½″ × 11″, 6 pages, covers inspection equipment for cloth-printing machines, including data on installing and operating stroboscope. General Electric Co., Schenectady, N. Y.

I-181 **Precision Temperature Regulator.** Form No. TR40, 4″ × 9″, 4 pages, describes, illustrates and prices temperature control device for general laboratory use, complete with relay, thermostat element, connecting cords, mercury and two extra glass bulbs — accurate within 1/50th of a degree. Eastern Engineering Co., 45 Fox St., New Haven, Conn.

I-182 **Variable Transformer.** Bulletin No. 149, 8½″ × 11″, 12 pages, describes and illustrates Powerstat auto-transformer for obtaining continuously variable output voltage from a-c. power lines, also covers various applications. Superior Electric Co., 130 Harrison St., Bristol, Conn.

I-183 **Cornell-Dubilier "Capacitor."** Vol. 5, No. 1, 16 pages, contains Part IV of "Analyzing Radio Noises," data on how to re-set push-buttons and other items. Cornell-Dubilier Electric Corp., New Bedford, Mass.

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I-185 **Arc Welding.** Bulletin No. 341, 8½" × 11", 4 pages, covers article on arc welding including the graphic method of recording elapsed time by means of maker's time recorder. The Esterline-Angus Co., Inc., Indianapolis, Ind.

I-186 **Non-Indicating Air-Operated Controllers.** Catalog 77-2, 7¾" × 10½", 8 pages, describes and illustrates controllers for temperature and pressure of the air-operated remote bulb type, including a schematic diagram showing a typical application, actual installation photograph and drilling and mounting dimensions. Brown Instrument Co., Wayne and Roberts Aves., Philadelphia, Pa.

I-187 **"The Ohmite News."** April 1941, 2 pages, contains article on Gustav Robert Kirchhoff, discoverer of Kirchhoff's Laws on the division of currents in a network of conductors, also items on power chokes and resistors. Ohmite Mfg. Co., 4835 Flournoy St., Chicago, Ill.

I-188 **"The Use of Ability and Aptitude Testing in Business."** Booklet, 8½" × 11", 16 pages, gives explanation of the scientific plan which is followed building "batteries" of tests for all types of sales, executive, clerical and production jobs. The Personnel Institute, Inc., 225 North Wabash Ave., Chicago, Ill.

I-189 **Self-Synchronous Apparatus.** Bulletin GEA-2176, 8" × 10½", 8 pages, describes and illustrates Selsyns for remote signaling, control and indication, listing various applications. General Electric Co., Schenectady, N. Y.

I-190 **Air Weight Control.** Bulletin B-268, 8½" × 11", 12 pages, describes and illustrates the air weight controller for foundry operation which automatically controls the weight of air being delivered to the cupola. The controlled air flow is continuously recorded on a chart, graduated in terms of standard cubic feet or in pounds per minute. The Foxboro Co., 46 Neponset Ave., Foxboro, Mass.

I-191 **"What Time Is It?"** Booklet, 5¼" × 7¾", 16 pages, gives prevailing time, including Daylight Saving, in principal cities of U. S. and cities and boroughs of Tri-State and Pittsburgh districts. Free to "customers and friends" of Peoples-Pittsburgh Trust Co., Wood St. at Fourth Ave., Pittsburgh, Pa.

I-192 **Aerovox "Research Worker."** Vol. 13, Nos. 1 and 2, contain Parts 1 and 2 of article entitled "Applications of the A.F. Test Oscillator," give data on prong-base midget electrolytic condenser and L-C checker for frequency-reallocation. Aerovox Corp., New Bedford, Mass.

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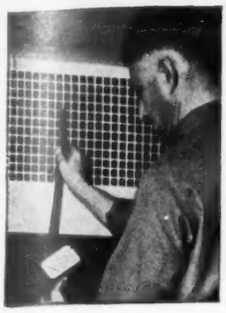

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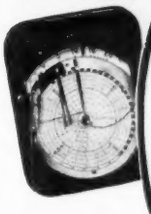

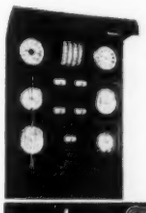

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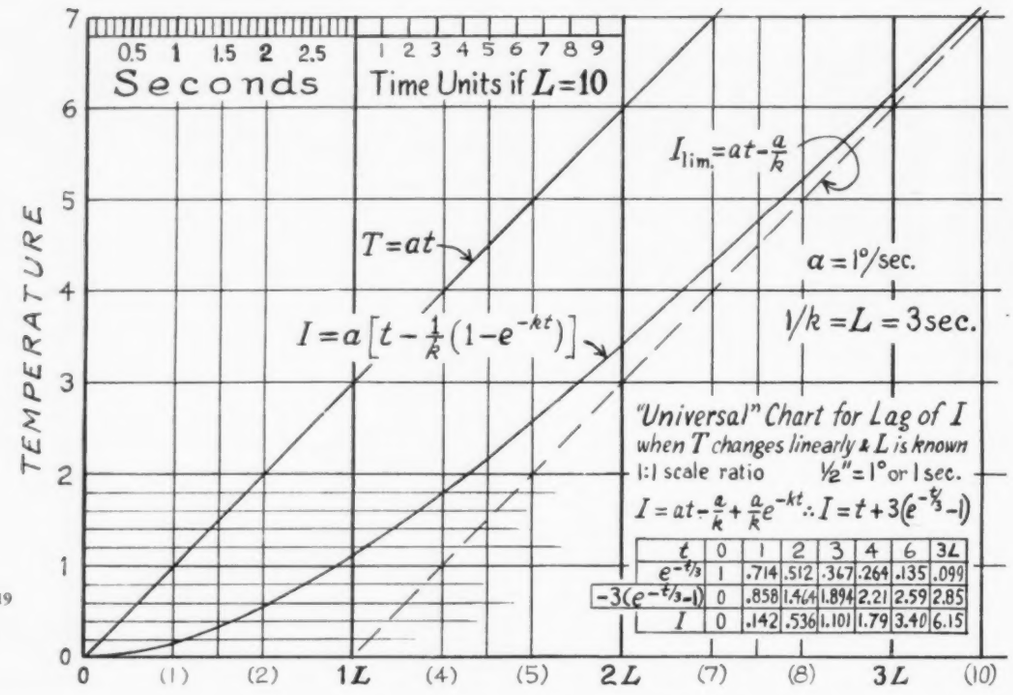
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Time Units if L=10
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a=1°/sec.
1/k=L=3sec.
"Universal" Chart for Lag of I
when T changes linearly & L is known
1:1 scale ratio ½"=1° or 1 sec.
I=at-a/k+a/k e^-kt ∴ I=t+3(e^-t/3-1)
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e^-t/3 1 .714 .512 .367 .264 .135 .099
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I 0 .142 .536 1.101 1.79 3.40 6.15
0 (1) (2) 1L (4) (5) 2L (7) (8) 3L (10)

Fig. 19

Solution.—A property of the thermometric lag equation is that the slope is determined by k (the reciprocal of L). Therefore, a family of pointer-response curves for one value of departure and various values of L is a "fan" of straight lines from the origin (initial temperature and zero time). This was already illustrated in Fig. 10. Such a diagram is easily made by drawing as many lines as there would be values of L (see discussion), after which the desired series is constructed by taking off the points with plain or proportional dividers. See Fig. 18.

Discussion.—The lag coefficient of a primary element as commercially obtainable is not "adjustable" (in the sense of turning a knob) but it varies according to the nature of the surrounding fluid, the amount of circulation, etc. The National Bureau of Standards, other institutions, and some instrument companies, have done and are doing research on these effects. Several tables have already been published. A compilation will be found in the Appendix. Knowing the lag of a particular primary element in (say) circulated water, its lag in other media can thus be obtained and, then, by referring to Fig. 18, a decision can be made as to whether the controller will be "fast enough" for a certain process.

The lag of a primary-element *assembly* is to a large extent "adjustable" by properly selecting materials, lengths, thicknesses, etc. Some instrument companies not only have a wide assortment of parts and fittings but have determined the coefficients of various items in various media.

Example VI

Data: Initial state: $I = T_0$. Instead of sudden departure, process disturbance causes temperature to change at a uniform rate until controller acts (or new equilibrium is established in process).

Required: Controller characteristics as before.

Discussion: As was shown in Section 4 of Chapter III, when $T = at$, the response is of the form

$$I = a\left[t - \frac{1}{k}(1 - e^{-kt})\right]$$

and as the value of t increases beyond $3L$ to $5L$, the exponential term becomes negligible. When this term vanishes,

$$I = at - \frac{a}{k}$$

which is the equation of a straight line. The straight portion of the I curve is then parallel to the T curve but displaced therefrom on the time axis in the "later" sense by $1/k$ (which is L), by reason of the negative term.

Solutions: The chart, Fig. 19, has been prepared to indicate the mathematical procedure and also to aid in graphic solutions. The degree and the second being ½", a decimal inch rule and proportional dividers will facilitate the construction of controller characteristic curves.

Functions other than L

Thermometric lag has been emphasized because its laws represent those of most time factors other than thermal, found in practice. For example the period due to pressure transmission lag is likewise inversely proportional to the amount of a sudden change. The equations given above may be adapted, for example, to oil refinery applications where a pressure in a remote unit must be controlled from a central control house. (Strictly speaking, the lag in the gage line from the unit to the pressure controller is part of the application lag—not a component of the controller period—but if the instrument engineer is told that it's *his* problem, logical or technical lines of demarkation must go by the board.)

The inverse-time relation is a desirable characteristic. It corresponds to the behavior of an intelligent human operator, who might make it a practice to "wait and see" whenever small departures from normality occur but would instantly perform a corrective function whenever a large departure occurs.

As a rule the converse is also true, that a dead time that varies *with* the amount of departure is an objectionable performance characteristic. At first thought it would seem impossible that any automatic controller would so behave, but such variable periods are met with in overdamped measuring systems, where the driving force causing pointer displacement varies as a lower power of the departure than the power as which the damping resistance varies. A controller with such a measuring system will remain inactive for a longer time in the event of a large sudden departure than in the event of a small sudden departure.

Note however that this has nothing to do with the total operative period of certain step-by-step controllers. One such controller, for example, might be so constructed as to send *uniform* impulses to its power device every two seconds; so that the number of impulses (and the total operative period required to complete the necessary corrective action) will naturally vary with the amount of departure. On some applications this is a desirable mode of control.

To be continued

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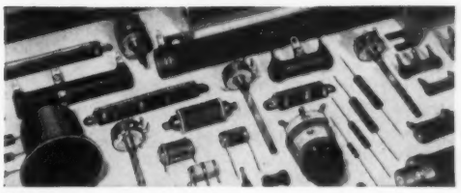

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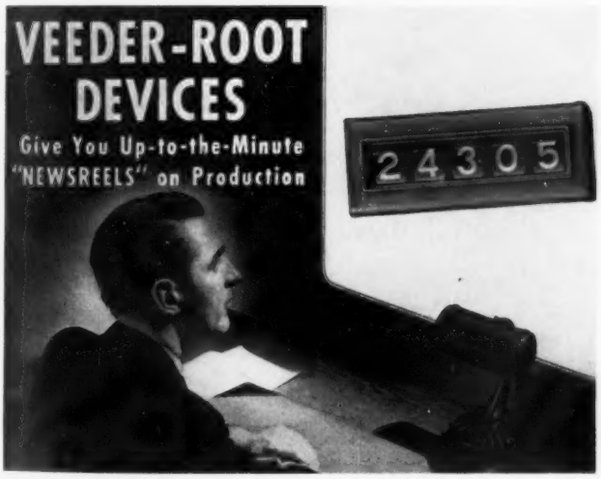

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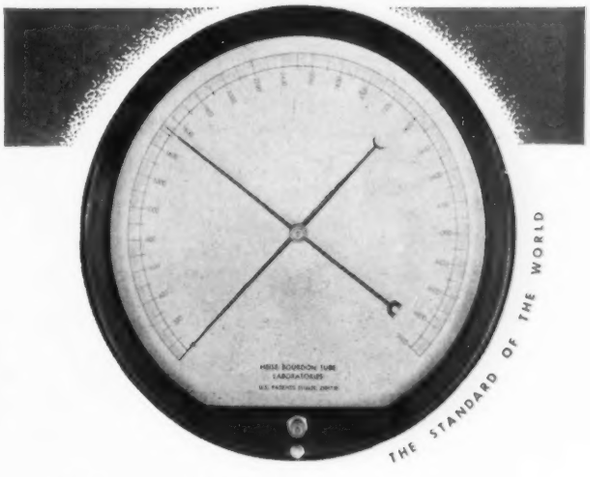

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IN COLLABORATION WITH THE A. H. EMERY COMPANY

INTEGRATOR FOR CIRCULAR ORDINATES

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flat face against the drum is moved tangentially to its outer surface by three thin, spring-steel bands or belts with opposite ends attached to the rod and to the drum and passing between them with opposing tension. Screw threads and nuts at the end of the two outer bands provide for drawing them tight. The rod will thus move a distance $y = r\,\theta$ where θ is the rotation of the tracer arm and drum and r is the radius of the latter plus half the thickness of the bands. This motion is smooth and free from back-lash.

The tracer arm of the integrator has a length equal to that of the pen arm of the wattmeter with which the curves were recorded. The point which follows the curves is the center of a circle about 1 mm. in diameter etched on the lower surface of a ½" glass plate. It has been found easy to see when the curve passes diametrically through this little circle. The instrument may be viewed from a convenient position and the strain on the operator from continuous use of the instrument is much less than it is with a metal point follower.

The connecting rod consisting of a ¼" drill rod and attached flat ground stock is guided perpendicular to the carriage guide and the time axis of the chart by two bearings on the carriage. The tracer point of the planimeter rides in a V-groove perpendicular to the connecting rod in a small plate attached to the latter and moving near the surface of the table. While this point moves in a circular arc, it will always have a component of motion parallel to the guide rod equal to the motion of the latter, and this distance divided by the length of the planimeter tracer arm is equal to sin ϕ mentioned above.

The planimeter polar arm rests with its center point in a conical socket in the carriage and is allowed to move vertically between rounded ends of screws so that the planimeter wheel rests with its normal weight on the surface on which it rolls. A smooth paper track is provided for the planimeter wheel. Shortened points are provided on both the tracer arm and the polar arm center to correct for the distance above the table surface. A weight is placed over the planimeter tracer point to insure its remaining in the V-groove. The arrangement permits easy removal of the complete planimeter.

CALIBRATION

Planimeters are usually adjusted to read areas in units of 0.01 in.^{2} per vernier division, or 10 in.^{2} per revolution of the planimeter wheel, which has 100 divisions. Then if y is measured in inches and if the carriage advances x inches along the time axis, the integrating wheel will advance 10 yx divisions or 0.1 xy revolutions. Since the integrator tracer arm must have a length equal to that of the pen-arm of the recorder, the only variable of design available for controlling the calibration is r.

The described integrator is designed for the following conditions:

Chart speed = 3 in./min. = 180 in./hr.
$\theta = 30°$ per kilowatt (width of chart is equal to length of pen arm, and full-scale deflection is 2 kilowatts)

If we trace a reading of dw watts for dt hours which is equivalent to $dwdt$ watthours, the planimeter reads as follows:

For dw watts: $dy = \frac{1}{1000} \times \frac{30\pi r}{180}\, dw$ inches

For dt hours: $dx = 180\, dt$ inches

(Area measured) $= \frac{30\pi r}{1000}\, dwdt$ square inches = 0.1 times the number of divisions of planimeter wheel.

It is found convenient to let one division of the planimeter wheel be equivalent to one watthour. The counter wheel which counts turns of the planimeter wheel to 10 will thus make one revolution for each kw hr. The value of r is found at once as $r = 100/30\pi = 1.061"$.

Two adjustments are necessary: First, the chart is placed so that the axis of the tracer arm moves along the center line of the chart or whatever line corresponds to the position of the pen-arm axis of the recorder, that is, the centers of the ordinate circles. Second, adjustment is made either of the drum with respect to the tracer arm or of the V-groove clamp at the planimeter with respect to the connecting rod, until no change in reading of the integrating wheel is obtained when the carriage is advanced while the tracer arm follower circle is set on the zero line of the chart. Calibration is easily checked by tracing along various fixed wattage lines of the chart.

RESULTS

The integrator has been found satisfactory in use. The accuracy was found to be about of the same order as that of the wattmeter, i.e., 0.5% of full scale, which is as good as one usually expects to get with instruments employing integrating wheels.

The instrument can be adjusted for zero reading at edge or at center of chart. It is necessary that the initial and final wattage reading for a given determination be equal, and usually curves are started and finished at the zero line. To partly correct for errors in placement of the charts and allow more latitude in this respect, it has been the practice to trace the zero line back to the starting point. It will be noted that the instrument as laid out here advances toward the right and traces the curve in a direction opposite to that in which it was produced, which is convenient in the case at hand.

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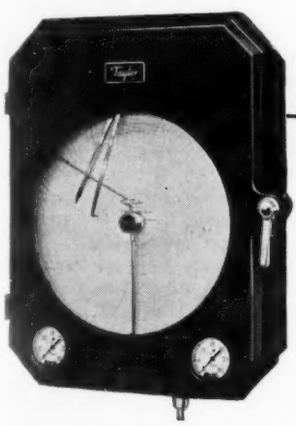

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